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INSTREAM AERATION TO CONTROL DISSOLVED
SULFIDES IN SANITARY SEWERS

Ray L. Condon, Jr., et al

Jefferson Parish Department of Sanitation

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INSTREAM AERATION TO CONTROL
DISSOLVED SULFIDES IN SANITARY SEWERS

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and development grant under the Federal Water Pollution Control Act as amended (466 et seq). On 27 June 1968 the Council accepted a FWPCA grant (WPRD-121-01(R1)-68).

The primary objective of this grant was to evaluate the effectiveness of various full scale methods of in-sewer aeration for reducing hydrogen sulfide problems and to develop design data for future designs. Facilities constructed and evaluated included two aspirated air U-tube systems for force main discharges, one in-line Venturi aspirator and one in-line Vortex-Shear aerator in a force main and one eductor or air-lift pump installed in a gravity sewer.

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16. Abstract Field studies were conducted employing full scale prototypes of four aeration devices installed in a sanitary sewage collection system. The devices used included an in-line Venturi aspirator, an in-line Vortex-Shear aspirator, an air-lift pump, and Venturi aspirated U-tubes. Only the Venturi aspirated U-tubes proved to be satisfactory under the conditions of this study. The U-tube installed on the end of a sewage force main reduced dissolved sulfides, at a sampling station 1500 ft downstream, from .30 mg/l to .02 mg/l (equivalent to a 12 min detention). Additionally, the U-tube virtually eliminated the stripping of H₂S in the discharge manhole where a severe odor problem and corrosive attack had existed. Oxygen demand in the force main immediately upstream of the U-tube averaged 2.5 mg/l. Oxygen transfer in the U-tube averaged 5.1 mg/l with residual dissolved oxygen in the effluent averaging 2.6 mg/l.

As installed, and with oxygen transfer averaging 5.1 mg/l, no modification of existing pumps was required. Higher transfer concentrations approaching 7 mg/l were obtained with Venturi aspiration, but resulted in increased pump head requirements. Transfer concentrations up to 8 mg/l were obtained with forced air injection, but did not appear to justify the added cost of blowers and greatly increased pump head requirements.

No maintenance was required on either of the two Venturi aspirated U-tubes during two years of continuous operation in this demonstration.

This report was submitted in fulfillment of ~~a grant to~~ Project Number 11010 ELP, Grant Number ~~WPRD 121-C1-68~~, under the sponsorship of the Environmental Protection Agency by the Department of Sanitation, Jefferson Parish, Louisiana, 600 Holois Street, Metairie, Louisiana 70005. The Project Director was Ray L. Condon, Jr. (EPA)

17a. Descriptors

*Sulfides ~~control~~, *odor ~~control~~, *corrosion control, aeration, *Sewers,*
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September 1973

INSTREAM AERATION TO CONTROL
DISSOLVED SULFIDES IN SANITARY SEWERS

by

R. L. Condon, Jr.
R. A. Cooper, Jr.
A. J. Englande, Jr.

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de Laureal Engineers, Inc. supervisory personnel involved in this demonstration were:

Mr. R. A. Cooper, Jr., Project Director
Mr. A. J. Englande, Test Supervisor
Mr. D. P. Boudreaux, Computer Programmer
Mr. H. A. Schomaker, Construction Supervisor
Mr. J. Gordon Hebert, Mechanical Engineer

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SECTION I

CONCLUSIONS

Dissolved sulfides above 0.1 PPM caused serious odor problems and costly corrosive attack to sewers and manhole structures. Turbulence from force main discharges and high gravity drops of sewage containing dissolved sulfides in concentrations of a few hundredths of a milligram per liter resulted in totally unacceptable levels of H_2S in the sewer atmosphere.

The Venturi aspirated U-tube, as designed and installed on the discharge end of two force mains, has demonstrated the ability to eliminate the turbulence characteristic of conventional force main discharges and to transfer sufficient oxygen to effectively oxidize the dissolved sulfides in the sewage stream. For dissolved sulfide concentrations up to 2 PPM the U-tube was effective without modification of pumps in existing lift stations. Experience indicated that if dissolved sulfides significantly above 2 PPM are encountered or if physical constraints are imposed on the U-tube design which limit the depth of the U-tube to less than 40 ft or the dimension from the centerline of the Venturi to the U-tube discharge to less than 6 ft, an increase in pumping head of 10% to 50% would be necessary. Of extreme significance to municipalities is the fact that the U-tubes in this demonstration required no maintenance in two years and did not burden the sewer system with additional mechanical or electrical devices that usually require considerable maintenance.

The air-lift aerator in this demonstration, while quite efficient in transferring oxygen to effect the oxidation of sulfides downstream, proved unacceptable because of excessive turbulence and consequent stripping of H_2S at the installation. The in-line Venturi aspirator and Vortex-Shear aerator installed in a force main did not achieve the same amount of oxygen transfer as obtained with the U-tube, and did not eliminate the turbulence at the force main discharge. The stripping of H_2S at the force main discharge makes the in-line configurations unacceptable.

In summary, the Venturi aspirated U-tubes in this demonstration proved highly effective and extremely economical in the control of dissolved sulfides at and downstream of force main discharges and merits serious consideration whenever odor and corrosive attack constitute a problem in sanitary sewage systems.

SECTION II

RECOMMENDATIONS

It is recommended that, in existing systems, the application of a Venturi aspirated U-tube be considered at the discharge of any force main that has a flow of 300 GPM or more and which causes or contributes to odor and corrosion problems. It is further recommended that, in the cases of new systems, the application of Venturi aspirated U-tubes to force main discharges be evaluated against the injection of air into force mains that have to be specifically designed for this application.

If a fairly constant flow, upwards of 500 GPM, and a differential head in the range of 6 to 8 ft are available the Venturi aspirated U-tube can be applied in gravity sewers, at points other than at force main discharges. However, variable flow and head requirements impose serious design constraints.

From observations in this demonstration involving U-tubes designed by Rocketdyne on the basis of techniques developed and reported under the title "U-tube Aeration" (3) it is recommended that actual system losses and flows be accurately determined in all existing systems and that the substitution of larger diameter pump impellers and increased motor HP be weighed against design constraints that might otherwise be imposed. Consideration should be given to increasing wet well volume to extend actual pumping time. In existing systems this should include the possibility of installing dual wet wells. The pumping time should be of maximum duration (at least ten minutes) consistent with an acceptable detention time of one or two hours in the wet well at minimum flow.

Finally, since the Venturi aspirated U-tube may not adapt to installation in gravity sewers other than at force main discharges, particularly in the case of existing systems, because of variation in flow and/or the differential head required, it is recommended that further study be conducted on the air lift aerator. This device accommodated a wide variation in flow and proved highly efficient. As

configured in this demonstration there was excessive turbulence and stripping of hydrogen sulfide, which despite the 20 ft high vent provided resulted in a discernible odor within a radius of several hundred feet during periods of high humidity and still air. It should be possible to reconfigure this device, minimize lift air, and provide a smooth discharge into the receiving stream similar to that achieved by the U-tubes. If this can be accomplished the air lift aerator would constitute a highly practical and efficient aerator readily adaptable to any new or existing gravity sewer and to any required spacing of aeration devices.

SECTION III

INTRODUCTION

In August of 1961 de Laureal Engineers, Inc., completed a master sewerage plan for the East Bank of Jefferson Parish, an area of 32,000 acres abutting and contiguous with the City of New Orleans. This plan embodied both future sewerage and immediate rehabilitation of existing facilities.

In the investigation incidental to the development of this plan the sewage collection system and Helios Treatment Plant serving the section known as "Old Metairie" were found to contain classic examples of corrosive attack and related deterioration caused by hydrogen sulfide generated in the sewage. This sewerage system and these conditions constitute the subject and basis for this study.

The collection system and Helios plant (activated sludge) had been completed in 1939. Soils in this area are generally soft to medium clays with silt and humus pockets and sand lenses. Running sands are sometimes encountered usually at depths below 12 ft. The terrain is flat. These conditions combine to dictate the use of minimal slopes just adequate to maintain a velocity of 2 FPS and limit the practical depth to which a sewer can be installed to about 12 ft. The result is a large number of lift stations and force mains. The force mains constitute a source of hydrogen sulfide and the gravity flow velocity is generally inadequate to control sulfide buildup. The Helios Collection System had a number of gravity lines carried to depths of 16 ft. These deeper sewers were in extremely unstable soils and over the years developed grossly uneven settlement and entrapment of sewage. Some larger sewers, of unlined concrete pipe, had collapsed or were found on the point of imminent collapse due to corrosive attack of the crowns. Similarly, a considerable number of manholes, particularly where force mains discharged into gravity sewers (discharge manholes), had been severely attacked and several totally destroyed. Streets had been undermined and the infiltration of sand had completely overwhelmed the treatment plant's grit removal facility. Except for short periods following a heavy rain, sewage arriving at the plant was highly septic, and treatment was virtually non-existent.

In July of 1963, contracts aggregating in excess of \$13 million were awarded to implement the immediate phase of the master plan. Approximately \$11 million was allocated to new sewerage. Somewhat over \$1 million went to rehabilitate the collection system, and a like amount was used to repair and update the treatment facility. The obvious and immediate needs in the collection system imposed a dilemma. A number of major gravity lines were beyond practical repair and had to be abandoned. The cost to remove and replace these lines was considered prohibitive, and as a result the system had to be reconfigured with the addition of new lift stations and force mains.

The new configuration significantly reduced the overall retention time of sewage in the system, improved velocities, and removed most, if not all, major sources of septicity from the gravity portion of the system. Sewage arriving at the plant was generally fresh. Odor at the plant was abated and effective treatment restored. Offsetting to some degree the marked improvement at the plant was immediate evidence of sulfide generation in the longer force mains and the stripping of hydrogen sulfide (H_2S) in the discharge manholes. The discharge manholes of two force mains which generated the most complaints about odor and which showed evidence of severe corrosive attack were ultimately designated as Stations 5 and 7 in this study. It is worthy of comment that the rehabilitation of the system was completed in late 1964. In July of 1969 field crews taking background samples for this study found both discharge manholes at Stations 5 and 7 brought to the point of imminent collapse by corrosive attack. Over one inch of mortar lining had been consumed, no mortar was visible between bricks in the upper two thirds of the manhole wall, and bricks had fallen from or could be removed with the fingers from the top course.

Prior to application by Jefferson Parish in March of 1968 for grant assistance from the then, Federal Water Pollution Control Administration (FWPCA), to conduct this study, there was clear recognition of the urgent need for effective control of sulfide generation in force mains. Investigation of possible methods suggested that aeration was by far the most feasible approach. In light of an article published by Laughlin in 1964 (1), first consideration had been given to aeration of the force main

by injection of air immediately downstream of the pump discharge. The City of New Orleans about this time began a series of extensive experiments in this application. Observation of these efforts forced the conclusion that air injection at the inlet of a long force main is feasible only if the force main is specifically designed oversize with a steady upgrade from the point of air injection to the discharge. The force mains in Jefferson Parish were neither suited or practically adaptable to aeration at the pump discharges.

Before abandoning aeration for a more costly chemical treatment, attention was turned to the possibility of aeration at or immediately downstream of the force main discharge. Research in this direction disclosed an article by Bruijn and Tuinzaad published in 1958 (2) relating to a U-tube aeration device. The device as described was not directly applicable to sewage, however, it appeared that a modified version adapted for use with a Venturi type aspirator would be uniquely applicable to the discharge of a force main. A preliminary evaluation suggested that the U-tube system had two potentially significant characteristics as follows:

First, the probability that H_2S would be oxidized and not stripped into the atmosphere. Almost certainly the evolution of this noxious gas would be significantly less than in a conventional discharge manhole.

Second, total system head loss could remain within the capacity of existing sewage pumps implying that aeration could be accomplished using energy otherwise dissipated and wasted in the discharge manhole. Even if this proved optimistic the fact that the installation required no additional mechanical or electrical equipment and at worst only a very nominal increase in power was extremely attractive to a utility already overburdened with cost and maintenance problems.

Information adequate to constitute a design basis for this and related sewage oxygenation devices could not be found in published literature. Accordingly application was made by the Jefferson Parish Council to the FWPCA for a research

SECTION IV

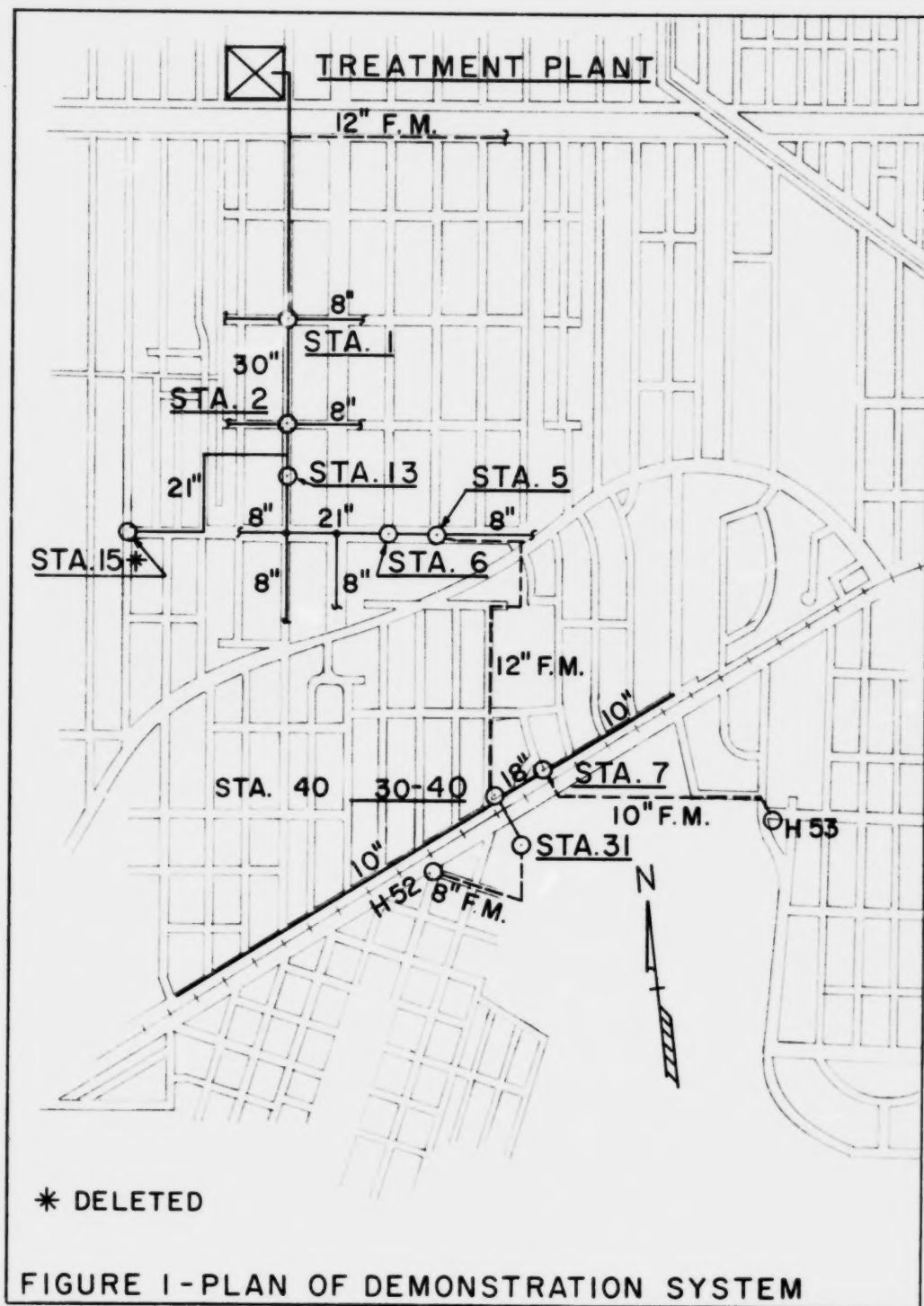
DESCRIPTION OF THE PROJECT

SELECTION OF TEST STATIONS

Figure 1 illustrates the configuration of the project and the location of test stations on a portion of the street map of the "Old Metairie" area of Jefferson Parish. A schematic flow diagram of the test sewers showing the aerator locations, sewers and approximate sewage flows is shown in Figure 2.

Station 1 is a manhole in a 30" gravity sewer located 1200 ft upstream from the Helios Treatment Plant and 835 ft downstream of Station 2. The average dry weather flow through Station 1 during the evaluation phase of the study was on the order of 3.0 MGD which corresponds to a liquid depth of about 14 in. in the pipe. Surge effect from upstream force main discharges appear to be largely damped out at this station. Four untreated gravity laterals contribute about .2 MGD or 7% of flow through Station 1. Accordingly with 93% of the flow through Station 1 from the air-lift aerator installed at Station 2 and 39% of this flow from the U-tube at Station 5, Station 1 was considered to be a key sampling station in evaluating the performance of the air-lift aerator and the cumulative effect of upstream aeration.

Station 2 is the location of the air-lift aeration device. This is the only station in a gravity sewer. In the original scope, Station 2 was spaced a calculated distance downstream of aerators at Stations 5 and 15 on the basis of a method proposed by C. L. Swanson (7). Ultimately Station 15 had to be deleted to remain within available funds. The spacing (2025 ft) downstream of Station 5 was retained for Station 2 although the basis for the calculation was largely invalidated by the omission of Station 15. The sewer at Station 2 is 30 in. and the dry weather flow was on the order of 2.8 MGD during the evaluation. Station 2 is located 185 ft downstream of the intercept of two 21 in. sewers and 525 ft downstream of Station 13. It is the unaerated flow of the 21 in. sewer from the deleted Station 15 (see Figure 1) that invalidated the



calculated spacing and which undoubtedly contributed to the odor problem subsequently encountered. Approximately 1.3 MGD of the flow to Station 2 is from Station 13 with upwards of 1.0 MGD of this flow from the U-tube installed at Station 5. Accordingly the ratio of treated to untreated sewage arriving at Station 2 was about 40-60. Because this station did not exist prior to installation of the aeration device, and extreme turbulence occurred after installation of the air-lift aerator, Station 2 was not considered a sampling station.

Station 13 is a manhole in a 21 in. gravity sewer located 1500 ft downstream of the U-tube installed at Station 5. Data from this station in conjunction with data from Stations 5 and 6 is the only basis for evaluating the calculated spacing for aeration devices developed by this demonstration. The average dry weather flow through Station 13 during test hours is about 1.3 MGD. Liquid depth during sampling ranged between 9 in. and 14 in. corresponding to flows of 1 and 2 MGD respectively. Approximately 0.2 MGD of the flow through Station 13 is from five untreated laterals entering the system downstream of Station 5 and 1.1 MGD from the U-tube at Station 5 thus approximately 80% of each sample at Station 13 is from the U-tube installed at Station 5, and Station 13 was selected to be the key sampling station in the evaluation of U-tube performance as well as aerator spacing.

Station 6 is the first manhole 370 ft downstream of Station 5. This location was selected to evaluate the performance of the U-tube at Station 5 because of the extreme turbulence generated by the discharge from the 12 in. force main at Station 5 before installation of the U-tube. The dry weather flow through Station 6 is about 1.1 MGD. Of this flow about 0.05 MGD is from an 8 in. untreated gravity sewer thus upwards of 95% of the flow through Station 6 is from the U-tube at Station 5.

Station 5 is the discharge manhole for 3000 ft of 12 in. force main from the pump station at Stations 30-40 and is the location of the larger of two Venturi aspirated U-tubes. The invert of the 12 in. force main into this manhole is 7 ft 2 in. above the sewer invert. The fall and splash of this stream accounted for the stripping of H_2S and a significant aeration at this station prior

to diverting the flow through the U-tube. The pumping rate through this U-tube averaged 1500 GPM during test hours and dry weather. After adjustment of the controls at Station 40, the duration of the pumping and off cycles ranged between five and nine minutes depending on separate or simultaneous discharges from Stations 7 and 31. Flow through the U-tube at Station 5 averaged 1.1 MGD. Taps were provided to determine pressure and to take samples upstream of the U-tube.

Stations 30-40 are the dual wet wells of the pumping station discharging to Station 5. Station 30 receives the force main discharge from Stations 31-32. Station 40 receives the gravity discharge from Station 7. The two wells are bottom connected by a 24 in. equalizer. The pump suctions are installed in Station 40. Both Stations 30 and 40 had been sealed and provided with 6 in. vents carried under a railroad embankment to an open area because of continuing complaints about odor from residents in the immediate vicinity. The force main discharge from Stations 31-32 is relatively high. Prior to aeration the free fall to the water surface in Station 30 was on the order of 4 ft at high water and 7 ft at low water. With the start of the aeration devices, the high water level was raised about 2 ft to prolong the pumping cycle. Low water remained as previously set. As a consequence, there was considerable turbulence in Station 30, both before and after activation of the aeration devices. The average dry weather flow through Stations 30-40 during test hours is about 1.1 MGD. Of this, approximately .5 MGD is a fairly uniform untreated flow from two 10 in. gravity sewers. The flow from the U-tube at Station 7 was intermittent, generally 9 min out of 21 at a rate of very nearly 0.7 MGD or an average of just under .3 MGD. The flow from the aeration device at Stations 31-32 was somewhat less frequent, generally 5 min out of 24 at a rate approaching 1.4 MGD or again an average of just about .3 MGD. It can only be assumed that a sample from either Station 30 or 40 taken near high water immediately after cessation of the force main discharge would have between 40% and 85% of aerated sewage depending on the separate or simultaneous discharge of the two upstream stations. Because of the questionable significance of samples from Stations 30 and 40, and the numerous complaints from residents in the vicinity about opening the sealed covers at these stations,

the taking of data after activation of the aeration devices was minimal.

Station 7 is the discharge manhole for 2050 ft of 10 in. force main from the pump station designated H53 on the plan. It is also the location of the smaller aspirated air U-tube. The pumping rate through this tube averaged just under 600 GPM. The duration of pumping averaged 9 min with an interval of 12 min between pumping.

Stations 31-32 are, respectively, pressure taps in the force main immediately before and after the in-line Venturi and Ashbrook Aerator located in an 8 in. force main 1220 ft downstream of pump station H52 and 300 ft upstream of Station 30. The pumping rate through the aeration devices ranged between 920 and 1080 GPM.

BACKGROUND DATA

The initial instrumentation for this project included 24 hr clock operated samplers and battery operated recording D.O. and temperature probes both purportedly sealed and suitable for operation in the sewer atmosphere. After repeated failures and repairs during the first months of sampling it became obvious that this instrumentation was totally unsuitable and that the sampling procedure would have to be revised. Reviewing available instrumentation it was decided to use specific ion electrodes with extended leads for sulfide, chloride and pH measurement directly in the sewer stream. No reliable data was collected during the summer of 1968.

In early spring of 1969 it became apparent that design data from Rocketdyne would not be received in time to permit advertising and construction of the aeration devices in time for evaluation that year. Field work was limited during 1969 to verification of sampling methods and procedures. The taking of samples to establish background data was initiated June 19, 1970 with the aeration devices under construction and scheduled for activation in August 1970. Background data, viz: data accumulated prior to activation of the aeration devices is tabulated on pages 86 thru 88 of Appendix B.

AERATOR DESIGN AND INSTALLATION

Design criteria for the U-tubes and Venturi aspirators was developed for this project by Rocketdyne under contract 14-12-434 with the FWPCA and is fully described in Rocketdyne Report entitled "U-Tube Aeration" (3). Spacing of the aerators was based on empirical methods developed by C. L. Swanson (7). Preliminary design data was received from Rocketdyne in May of 1969. It was immediately apparent that the configuration developed by Rocketdyne for the aspirated U-tube was vastly more sophisticated than had been envisioned and would greatly exceed the estimated cost, however, since all other aspects of the design were complete including spacing of the devices, it was decided to advertise for bids and, if necessary, either solicit additional funds or negotiate the elimination of certain facilities to remain within available funds.

FWPCA and Louisiana State Board of Health approvals were received in July of 1969 and initial bids received on August 21, 1969. All bids were grossly excessive and could not be negotiated. As a consequence all bids were rejected. The project was reduced in scope and readvertised. New bids were received November 13, 1969. On this occasion two of four contractors submitted bids in line with estimated cost and within budgeted funds. The contract was awarded to the low bidder, Pratt Farnsworth, Inc. of Metairie, Louisiana. Construction was initiated in March and completed in August of 1970.

It is worthy of comment here that the high bids initially received from all contractors and subsequently from two of the four bidding the readvertisement can be largely attributed to an understandable concern over the requirement to sink 3 ft to 4 ft diameter casings for the U-tube to depths of 50 ft in developed residential areas. In actual fact, no problems were encountered and indications are that the casings could have been extended to considerably greater depths without difficulty.

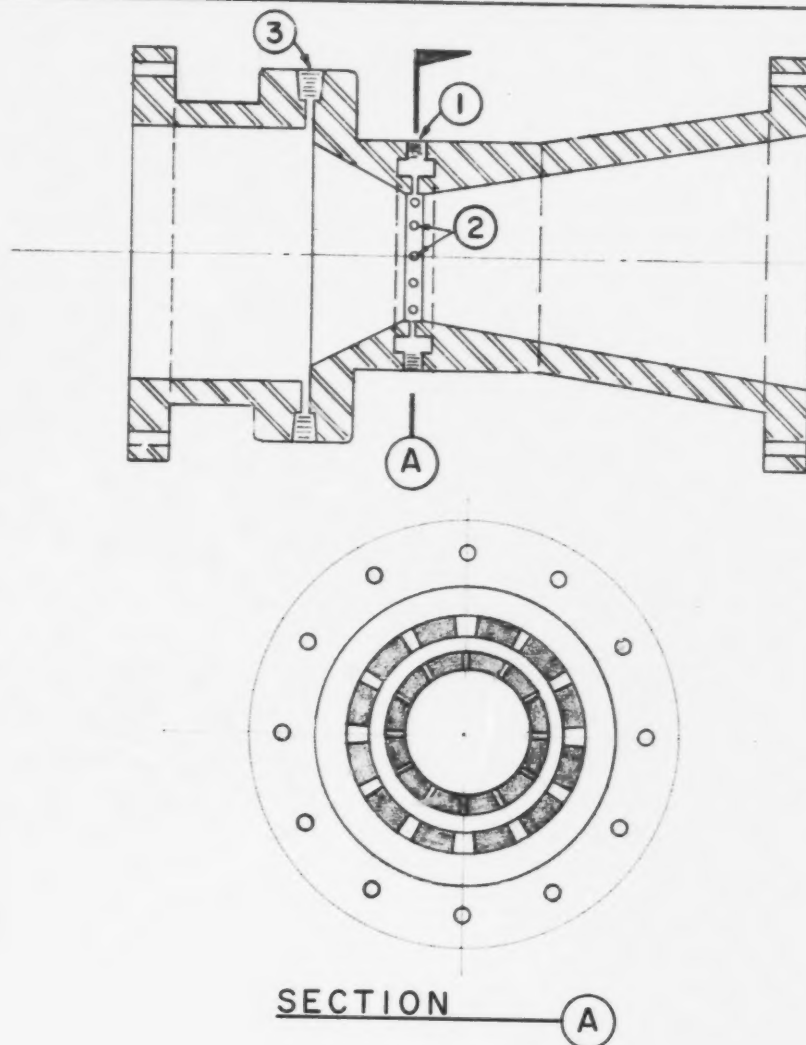
The U-tube has three characteristics essential to effective transfer. First, pressure resulting from a head of water; second, a homogenous dispersion of air as bubbles due to vertical flow; and third, an extended contact time due to the inherent rise rate of the bubbles opposing the direction

of an only slightly greater rate of liquid flow in the down leg of the tube.

The Venturi aspirated U-tubes as installed at Stations 5 and 7 are illustrated in Figures 4 through 7. The Venturi is shown in Figure 3. Basic design objectives and constraints include:

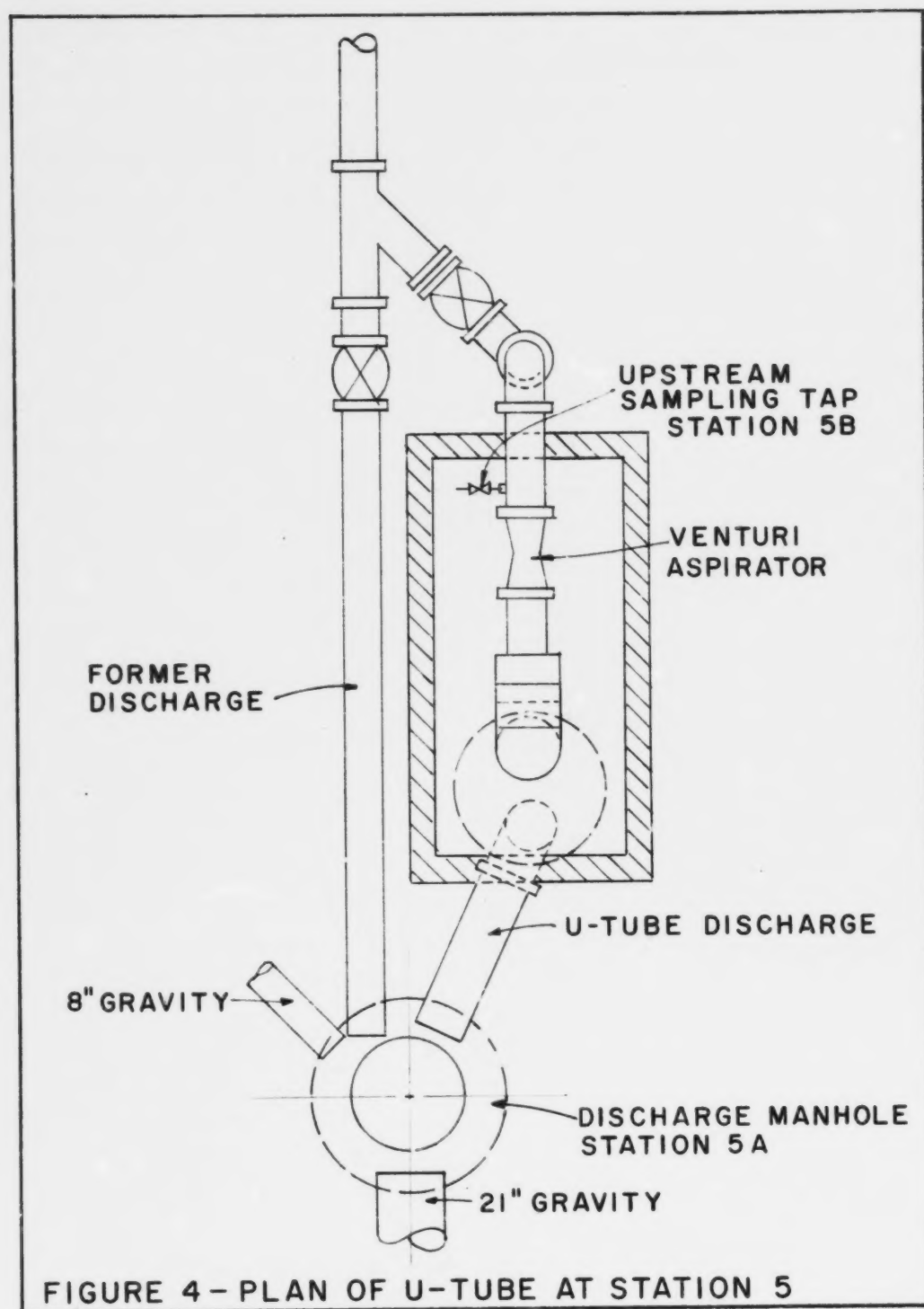
- a) A Venturi throat pressure below ambient to aspirate the required volume of air; in this demonstration to realize an air/water volume ratio on the order of 0.1.
- b) A smooth flow line that will freely pass stringy material.
- c) A Venturi throat diameter that will pass a 3 in. or in some cases 4 in. diameter sphere. In this demonstration 4 in. was used.
- d) A down leg diameter that will produce the minimum velocity adequate to maintain optimum entrainment of the air bubbles. In this demonstration a value between 1.5 and 2.0 FPS was used based on experimental work by Rocketdyne (3).
- e) A return bend and up leg diameter that will insure a velocity adequate to transport grit and larger solids likely to be encountered in sewage, in this demonstration 4 FPS.
- f) A casing of maximum practical depth to increase pressure within the U-tube and enhance oxygen transfer. In this demonstration the target depth was 50 ft and actual depth realized 43 ft and 57 ft for Stations 5 and 7 respectively.
- g) The maximum vertical distance obtainable between the centerline of the Venturi and the centerline of the U-tube discharge. In this demonstration dimensions of 9.5 ft and 7.0 ft were used for Stations 5 and 7 respectively. This dimension will significantly effect the total head loss through the system and consequently Venturi design.

PVC, suitably reinforced with fibreglass, was selected for construction of the U-tubes.



- 1 ASPIRATION INLET
- 2 ASPIRATION PORTS · SPECIAL DRILLING
- 3 UPSTREAM TAP · STANDARD DRILLING

FIGURE 3—DETAILS OF VENTURI ASPIRATORS



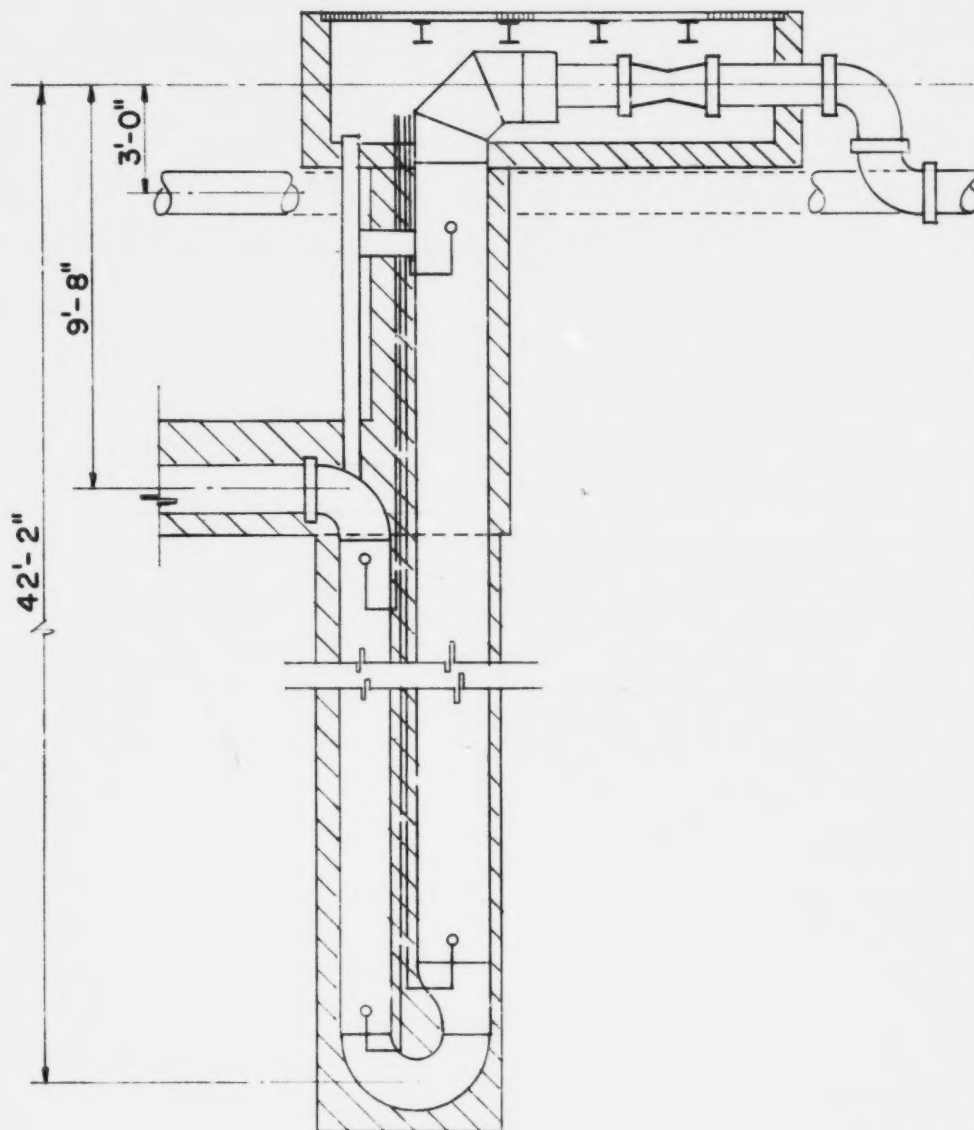
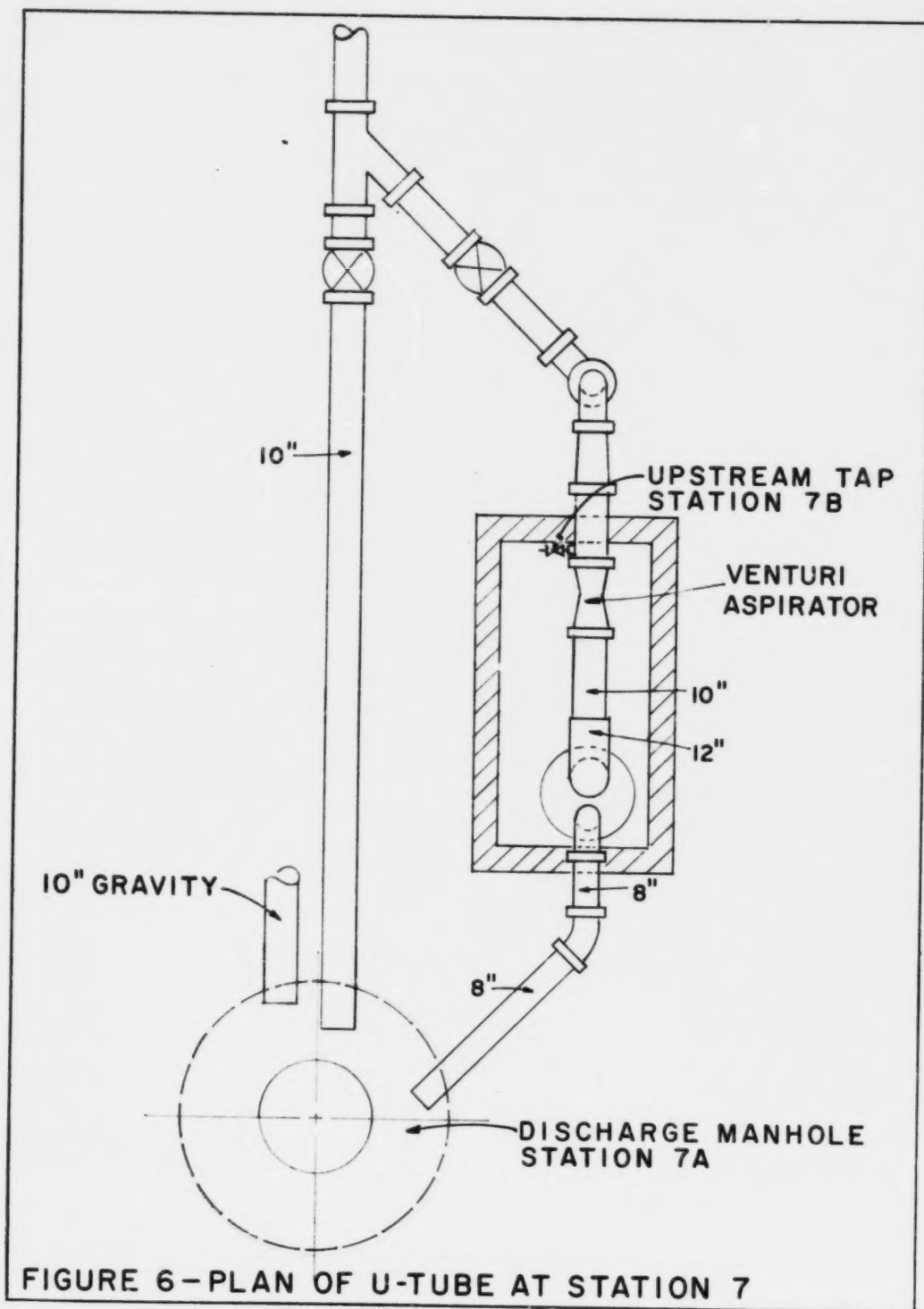
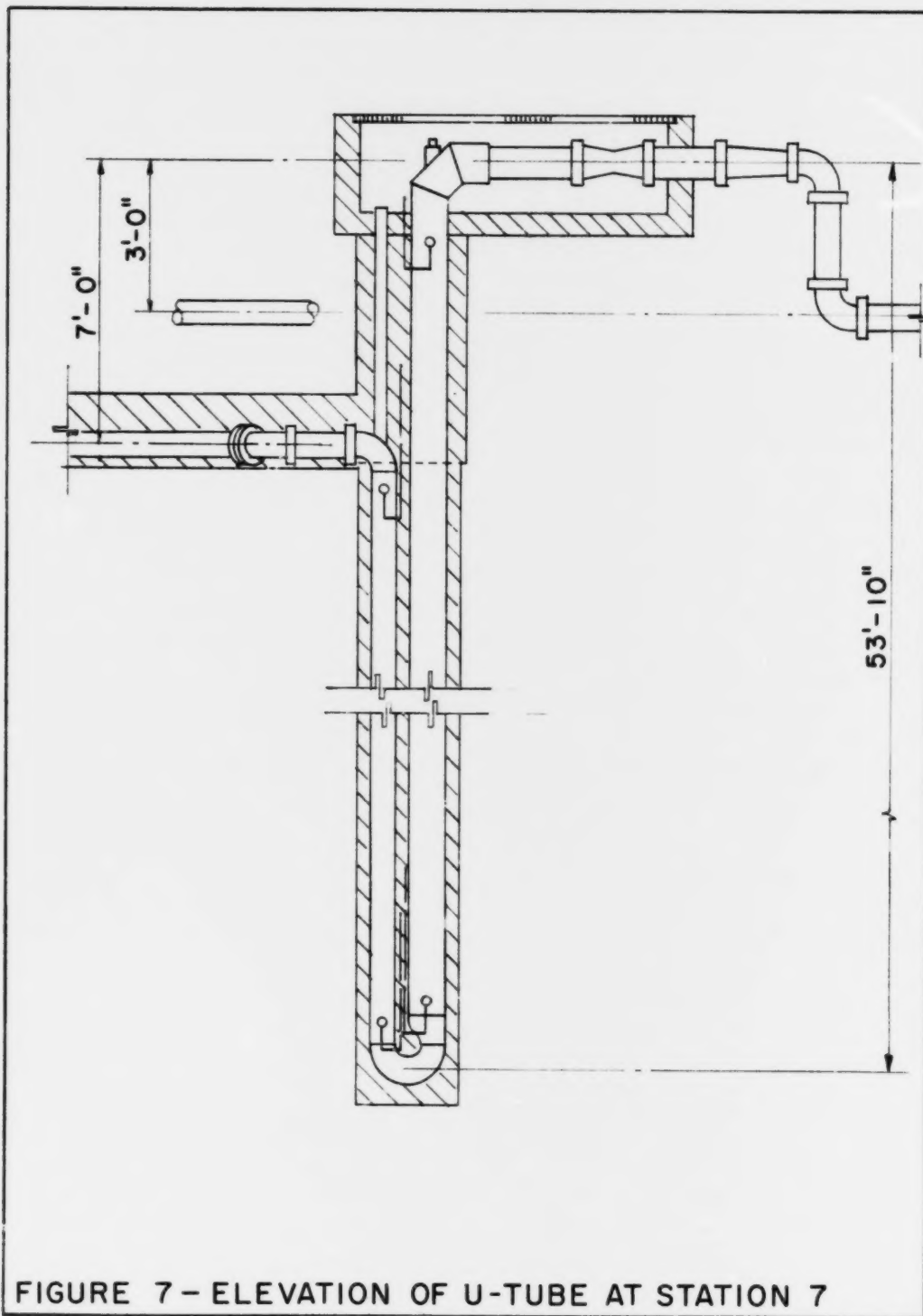


FIGURE 5 - ELEVATION OF U-TUBE AT STATION 5



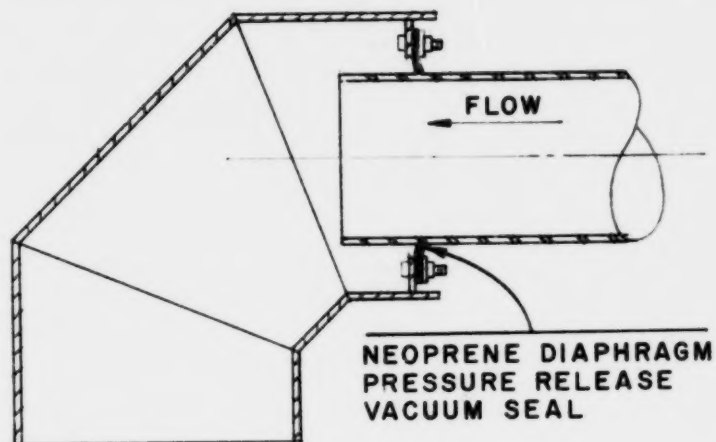


Taps were provided to permit pressure readings at the Venturi throat, after the Venturi, at the top of the down leg, at the bottom of the down leg, at the bottom of up leg and at the top of the up leg. There is also provision for metering the aspirated air to the Venturi throat. The original configuration provided a relief collar at the entrance to the U-tube (see Figure 8). This collar released entrapped air from the down leg then sealed as syphon action was established. This seal was removed the first week in November 1970 and the U-tube piped solid to the Venturi in an unsuccessful attempt to increase the volume of air aspirated. A final modification in November of 1971 (see Figure 9), also aimed unsuccessfully at boosting the volume of air aspirated, shifted the increase from Venturi outlet size to down leg diameter from ahead of to after the entrance elbow.

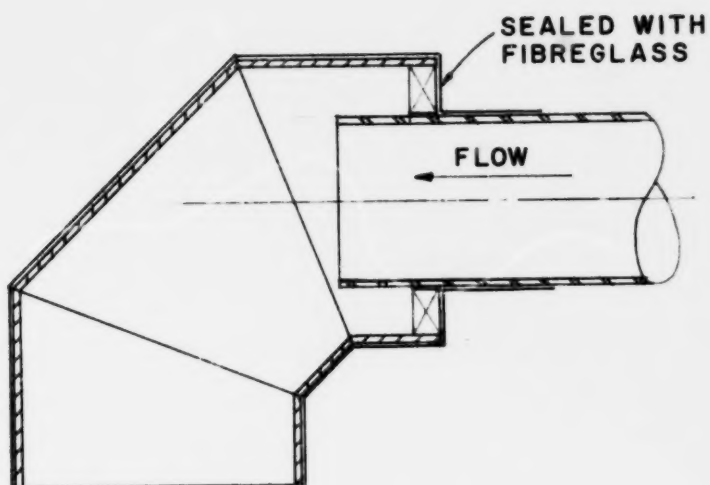
The steel casings for the U-tubes were jetted down, open ended, using hydrant pressure with occasional light driving, then cleaned by jetting and pumping, maintaining the casing full of water at all times to resist soil pressure at the bottom. The U-tubes were sunk in the water filled casings and maintained full of water with slight positive pressure during placement of concrete. Concrete was placed by means of a tremie with a 6 in. tube on alternate sides of the U-tube in about 4 ft lifts. At Station 5 the first six yard load filling 25 ft of the casing was placed without incident. When placement of the second load was started an hour later several feet of defective seam opened in the down leg just above the 25 ft level. About half a yard of the second pour entered the U-tube plugging it solidly. This necessitated replacing the U-tube and sinking the 48 in. diameter casing now half filled with concrete to a depth of over 75 ft to permit installation of a new 50 ft U-tube. The operation was stopped at 68 ft when low pressure jetting became ineffectual.

The tube length was reduced to 43 ft. It is apparent from this experience that open ended casings can practically and economically be sunk to depths well in excess of 50 ft in these soils, even in fully developed residential areas as was the case in this demonstration. No problems were encountered at Station 7 with the depth increased to 57 ft.

The Venturi aspirators employed with the U-tubes are essentially standard Dall flow tubes, product series 121 as

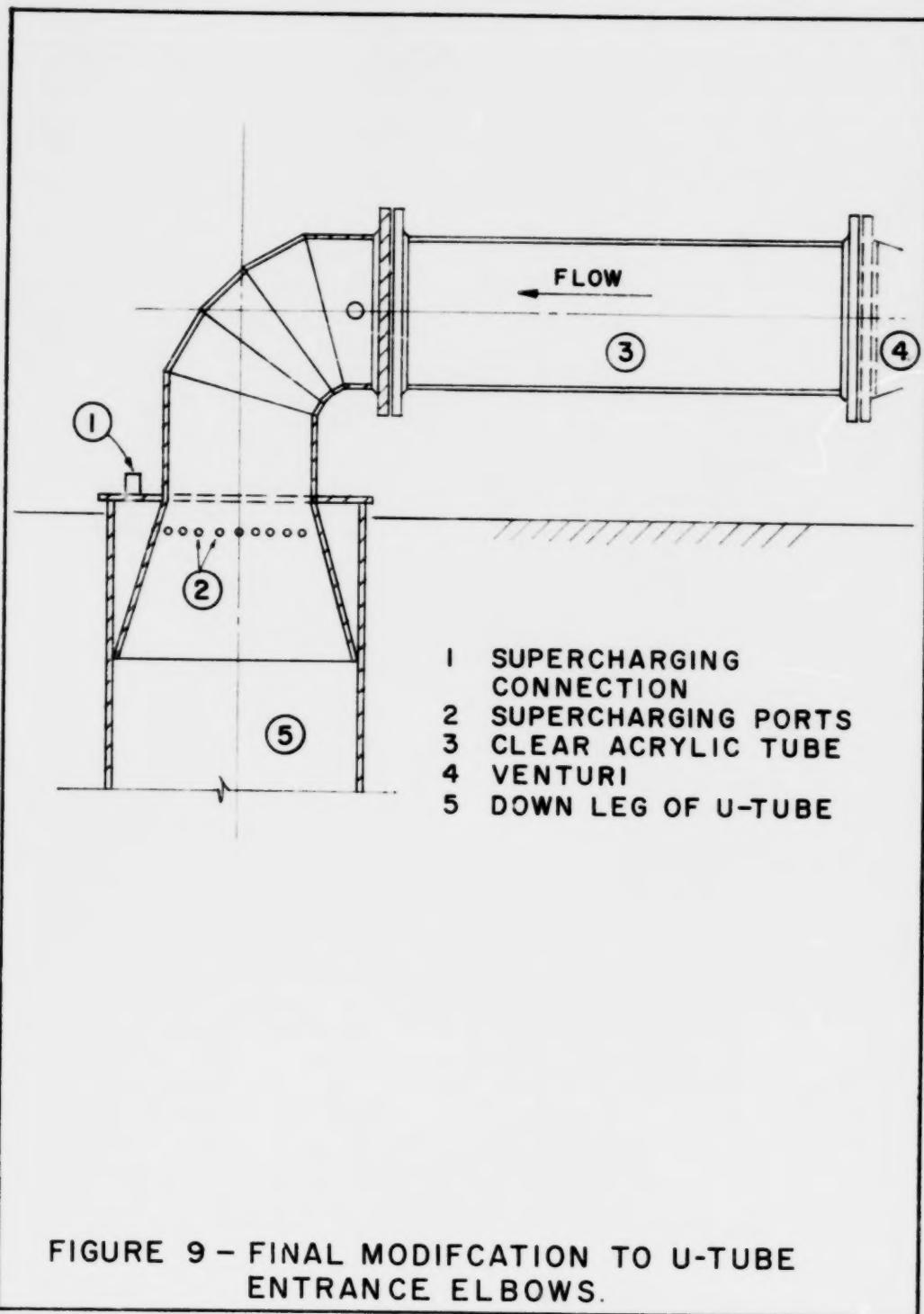


ORIGINAL ENTRANCE ELBOW



INTERIM MODIFICATION

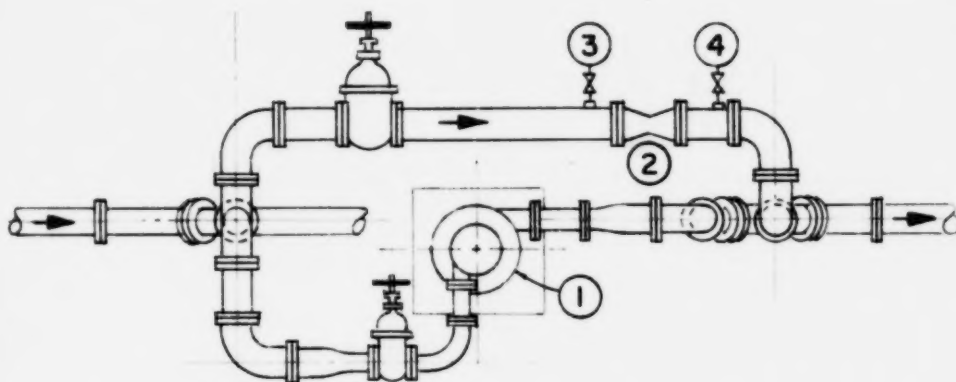
FIGURE 8 - ORIGINAL U-TUBE ENTRANCE ELBOW
AND INTERIM MODIFICATION



manufactured by BIF. These tubes were modified by drilling additional ports to augment aspiration as illustrated in Figure 3.

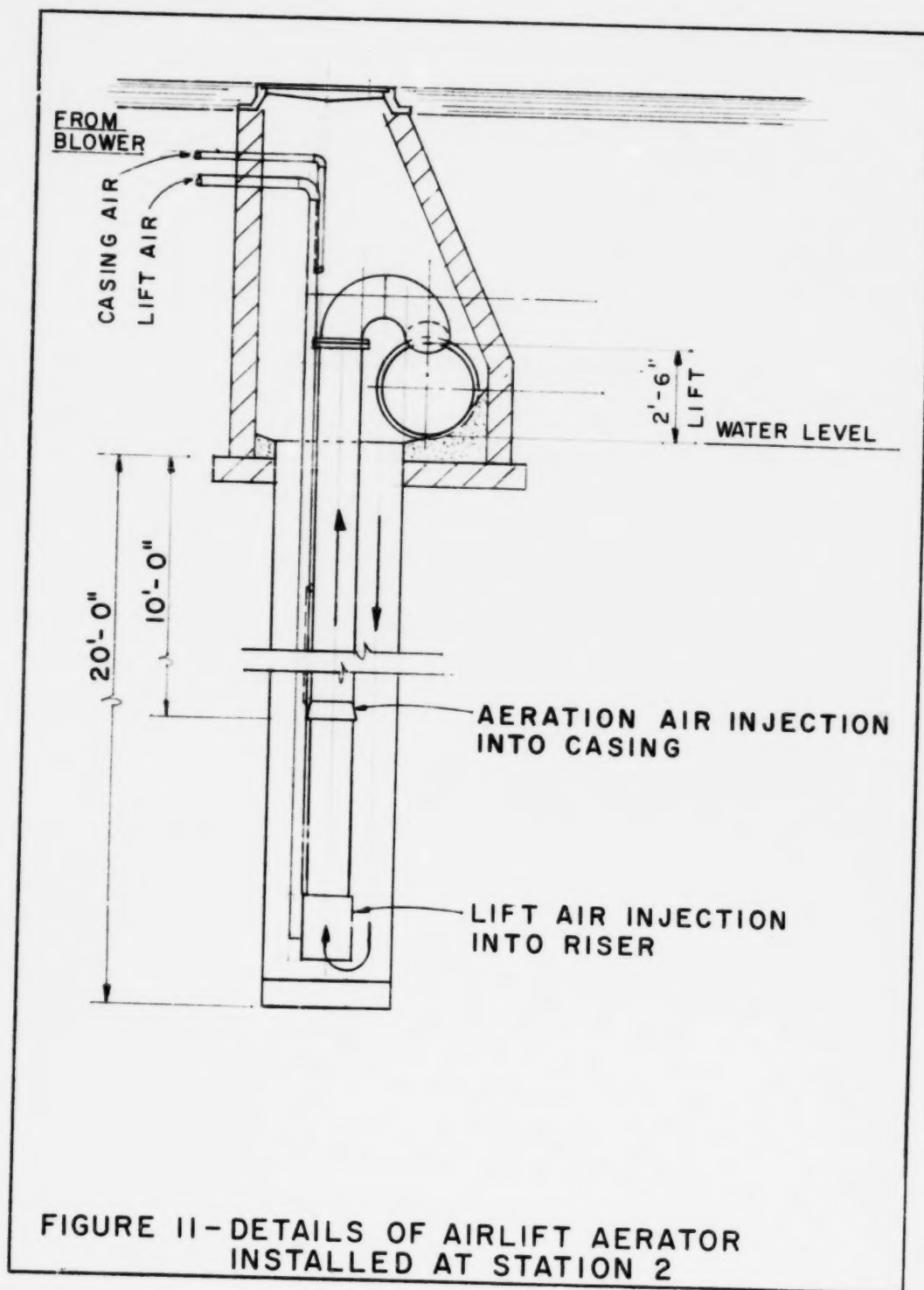
The in-line Venturi aspirator installed at Station 31 and shown in Figure 10 is basically similar to those applied to the U-tubes, but installed 300 ft from the discharge of the force main. The 300 ft of pipe downstream of the Venturi replaces the U-tube as a reaction chamber. As in the case of the U-tubes, the vertical distance from the centerline of the Venturi to the centerline of the force main discharge is critical. By locating this Venturi 4 ft 0 in. above grade at Station 31, a total drop of 12 ft to the force main discharge in Station 30 was realized. Also installed at Station 31 and shown in Figure 10 is an Ashbrook "Inlinator". This is a patented device operating on the Vortex-shear diffusion principle offered by the Ashbrook Corp. of Houston, Texas in a variety of standard sizes and configurations. The 1000 GPM unit installed in this demonstration involved reduction from the 8 in. force main to a 4 in. inlet nozzle and, according to the manufacturer, required an upstream pressure of from 15 to 20 psig. In operation the upstream pressure was 13 psig with a flow of 910 GPM. In this regard, the Ashbrook device does not compare favorably with the U-tube and in this demonstration failed to aspirate. A brief experiment in which air from high pressure bottles was injected at 30 psig immediately upstream showed a transfer of 4 mg/l D.O. Since the Ashbrook would not aspirate and since the continued injection of air from bottles would have been impractical and costly, no further evaluation of this device was made.

The aeration device installed at Station 2 and illustrated in Figure 11 is a modified airlift pump designed to accommodate the full flow of the sewer with a lift of 2 ft 6 in. The incoming sewage flows down the casing, is air lifted up the riser and discharged into the leaving gravity sewer. The 2 ft 5 in. lift was provided only to permit a support system clear of the flowing stream so that stringy materials would not be trapped. This proved to be a mistake and undoubtedly contributed to the stripping of hydrogen sulfide that rendered this configuration of an air lift unacceptable. Otherwise performance was excellent. The air lift concept, if the stripping of H_2S can be controlled still appears to be the best compromise for aeration at



- 1 ASHBROOK AERATOR
- 2 VENTURI AERATOR
- 3 UPSTREAM TAP
- 4 DOWNSTREAM TAP

FIGURE 10 - PLAN OF STATION 31



selected points in an existing gravity sewer at locations other than force main discharges. The airlift permits injection of the air at almost any depth to optimize oxygen transfer. This configuration uses a casing depth of 20 ft. The requirement to maintain a velocity of 4 FPS in vertical risers is obviously detrimental from the standpoint of retention time if a strictly conventional airlift is used. Accordingly the airlift for this demonstration was modified to provide for injecting aeration air into the casing or down leg 11.5 ft below the operating water level and 8.5 ft above the bottom of the casing. With a 24 in. casing and a 14 in. lift pipe, the down leg velocity in this case was roughly 1.6 FPS opposed to a bubble rise rate taken at .8 FPS or a net bubble travel rate of .8 FPS. Thus, retention time in the maximum pressure zone below 11.5 ft was approximately 12 seconds.

The volume of air required in a conventional airlift can be approximated from the equation $V = H/250 \log((S+34)/34)$ where V = volume of air in cubic feet per gallon of water, H = the lift above operating water level in feet and S = submergence below operating water level in feet. The optimum air/water volume ratio for oxygen transfer was taken at something less than .20. Higher ratios were not necessary to supply the required oxygen and would present the possibility of slug flow rather than the desired even dispersion of small bubbles. Accordingly this application is modified by injecting air to a maximum of 20% by volume 11.5 ft below operating water level. The effective submergence is taken to be 11.5 ft with a s.g. of 1.0 plus 8.5 ft with an s.g. of .8 or 18.3 ft in lieu of 20 ft. With a lift of 2.5 and a Q of 1500 GPM, the volume of lift air required is $2.5/(250 \times .1875)$ or .053 CF/Gal. and $1500 \times .053 = 79.5$ CFM. Aeration air required is 20% and $1500/7.48 \times .2 = 40$ CFM. Total air required = 119.5 CFM. The starting head for this airlift is 20 ft H_2O or 8.87 psig.

No problem was encountered in sinking the aerator casing which could and as events subsequently demonstrated probably should have been sunk to at least 50 ft to increase the contact time under increased pressure for greater transfer of oxygen into the sewage stream. One comment is in order about operation. Aeration air must be admitted after the lift is in operation and then with caution as this air is entering against a significantly lower pressure than

the lift air and excess air in the downleg will render the air lift inoperable. A sensitive control valve for accurate metering of aeration air is essential.

The aerator at Station 2 was spaced in relation to the aerator at Station 5 with the objective of maintaining a residual D.O. of 1.0 mg/l in the sewage. No basis per se for calculating the required spacing of aeration devices in a sewer system could be found in published literature. However, on the basis of existing publications on sulfide production and control, Mr. C. L. Swanson, the EPA Project Officer at the time, developed and submitted an empirical method (7) for approximating the required spacing of aeration devices. This method was employed in locating Station 2 with relation to Stations 5 and 15 in the original scope of this project. Unfortunately, it was necessary to delete a number of stations including Station 15 to remain within available funds.

Because of the elimination of Station 15 and the entry of the untreated 21 in. stream from Station 15 between Stations 2 and 13, Stations 5A and 13 were selected to evaluate this method for calculating the required spacing of aeration devices. A discussion and evaluation of Swanson's method (7) for calculating required spacing of aeration devices is contained in Section VI of this report.

The actual installed cost of the several aeration devices is tabulated below:

Station 5 - Aspirated air U-tube installed on the end of a 12 in. force main. Flow = 1700 GPM, depth = 43 ft. Installed cost - \$16,000.00.

Station 7 - Aspirated air U-tube installed on the end of an 8 in. force main. Flow - 650 GPM, depth = 57 ft. Installed cost - \$11,000.00.

Station 31 - Venture aspirator installed in an 8 in. force main. Flow = 1000 GPM. Installed cost - \$7,000.00.

Ashbrook aerator installed in an 8 in. force main. Flow = 1000 GPM. Installed cost - \$9,000.00.

Station 2 - Eductor or air-lift pump installed in a 30 in. gravity sewer. Maximum and average dry weather flow = 2000 GPM and 1500 GPM, respectively. Installed cost - \$13,000.00.

TEST PROCEDURES

Readings of temperature, flow, pH, D.O., BOD₅, COD and sulfides were taken at the selected stations shown in Figures 1 and 2 before and after aeration. Additional readings of immediate oxygen demand (IOD) and D.O. were taken before and after each aeration device.

D.O. and IOD measurements were made using the Azide modification of the Winkler Method. IOD samples consisted of 100 ML of sewage diluted with 200 ML of aerated distilled water in a standard 300 ML BOD bottle. DO measurements were made five and ten minutes after combination. IOD was determined by the following equation:

$$IOD = \frac{300 DO_1 - 200 DO_2}{100},$$

where DO₁ is the DO of the mixed 300 ML sample and DO₂ is the DO of the dilution water, usually at or near saturation.

COD determinations were made per Standard Methods (4) using the dichromate reflux method.

BOD₅ determinations were made per Standard Methods.

Pressure drops and air aspiration rates for the Venturi and Ashbrook devices were recorded. Finally, pressure readings were taken by personnel from Rocketdyne to determine actual head losses through the U-tube. Head loss data through the U-tube has been compiled and reported by Rocketdyne in their report on "U-tube Aeration" (3). Samples for determination of D.O., IOD, BOD₅, and COD were taken in standard 300 ML BOD bottles. The bottles were either immersed in the stream or filled from pressure taps with hoses extending to the bottom of the bottle to minimize aeration in sampling. For BOD₅ and COD determination, the completely filled bottles, free of air bubbles, were sealed and packed in ice for transport to the lab. D.O. and IOD determinations were run in the field.

pH and sulfide determinations were made using electrodes either in stream or in a plastic beaker at the pressure taps. In the latter case, a hose extended to the bottom of the beaker which was filled and slowly overflowed with the electrodes immersed well below the surface. The pH electrode used was Corning No. 476027. The sulfide electrode was Orion Model 94-16. The reference electrode in both cases was Orion 90-02. Orion Specific Ion Meters Models 404 and 407 were used for sulfides and pH respectively. The Orion 94-16 sulfide electrode is represented by the manufacturer to be essentially interference free and capable of stable readings down to a sulfide concentration of 10^{-7} moles per liter. The electrode develops a potential proportional to the activity of the sulfide ion in the sample. The electrode does not respond to bound or complexed sulfides, however with pH and ionic strength known, the total dissolved sulfides (the sum of H_2S , HS^- and $S^{=}$) can be computed. This relationship is shown in Figure 12. The electrode responds only to sulfide ion ($S^{=}$) and in this demonstration within the shaded band on Figure 12.

In domestic sewage with a pH at or below 8, ionic strength is not too significant and need only be approximated. For example, if an ionic strength of 10^{-3} moles per liter is assumed, then variations in ionic strength over the full range of 10^{-2} to 10^{-4} moles per liter would introduce an error of 6% or less in the determination of total sulfides.

On the other hand, for any ionic strength in the range of 10^{-4} to 10^{-2} moles per liter, a variation between a pH of 6 and 8 represents a range of roughly three powers of ten in sulfide ion activity and extreme accuracy in the measure of pH is essential.

Since high dosage with NaCl was involved in this demonstration in determining time of travel (detention time), ionic strength (I.S.) was programmed on the basis of measured chlorides with:

$$I.S. = CL^-(mg/l)/35457$$

The above formula empirically converts mg/l CL^- to solution

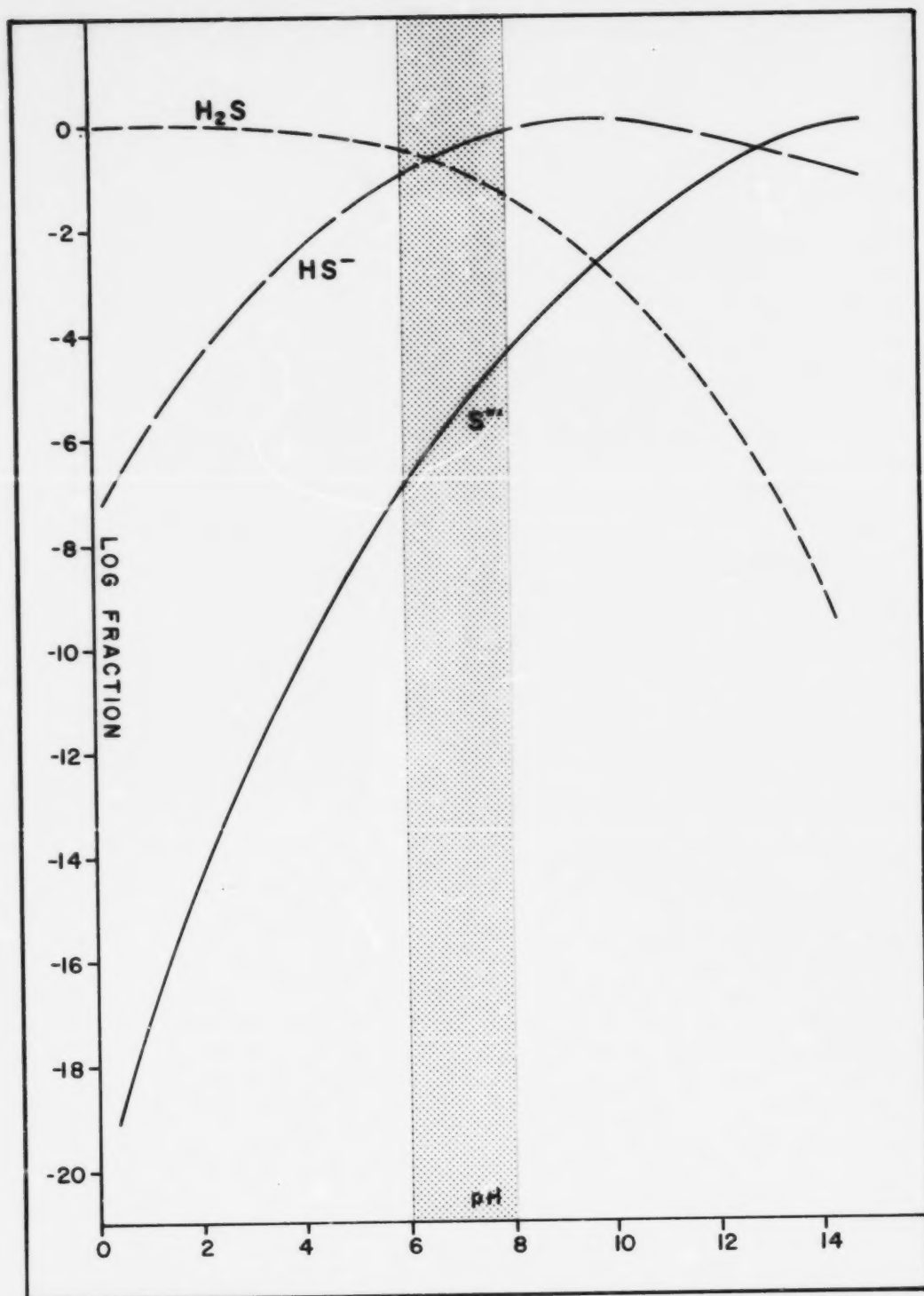


FIGURE 12-LOG FRACTIONS OF DISSOLVED SULFIDES

ionic strength in moles per liter. The result in the case of NaCl is identical with that derived by converting mg/l CL⁻ to mg/l NaCl then computing mg/l Na⁺ and applying the formula: ionic strength = $\frac{1}{2} \sum Z^2 C$. After dosage with NaCl was terminated measurement of chloride concentration was discontinued. The average value of background chlorides (200 mg/l) was assumed for all subsequent sulfide measurements, i.e., an ionic strength of 5.6×10^{-3} moles per liter. To verify the above formula a composite sample was made up of six samples taken hourly at Station 1 on July 16, 1970. Chlorides were measured in stream concurrently with the individual samples. The conductivity of the composite sample was 580 micromhos equivalent roughly to an ionic strength of .007M. The average of the six chloride measurements was 236 mg/l and $236/35457 = .0066M$. All pH measurements were read to two decimal places. This is well within the capability of the Orion 407 which has an expanded pH scale with a full scale deflection of 2.

With the exception of the Orion 90-02 reference electrode, no problems were encountered in this instrumentation. These reference electrodes appear to be somewhat vulnerable to the sewer environment, and required constant verification and frequent replacement of the outer filling solution (10% KNO₃). Since the same reference is used with both the pH and sulfide electrodes, the stability of the reference electrode can be verified with standard pH solutions.

It is worthy of comment that the Orion 404 meter can be calibrated in the lab for direct readout of total sulfides, using sulfide standards, however, standards for field verification would have to be at or above a pH of 13 to be reasonably stable. At pH 13 the resulting potential is in the vicinity of -800 MV which is beyond the maximum (-700 MV) scale of the 404.

In this demonstration, the sulfide electrode was calibrated in the lab using an Orion Model 801 meter which has a range of -999.9 to +999.9 MV and standard sulfide solutions of .001, .01 and .1 mg/l all at a pH above 13. The calibration was incorporated in the computer program (Appendix A) which was used to calculate total dissolved sulfides from the field measurements in absolute millivolts using the sulfide electrode and the Orion 404 meter.

Like any biological function, the generation of sulfides is temperature dependent, and since the purpose of this demonstration is to evaluate the effects of aeration on sulfides, the effects of temperature must be accounted for by standardization to a base temperature. For this demonstration, a base temperature of 85° F was selected since this was the average of all sewage temperatures before activation of the aeration devices. All instream sulfide measurements have been standardized to 85° F by application of the formula:

$$S_{85} = S(1.093^{85-T}),$$

where S = total dissolved sulfides as computed from instream measurement of sulfide ion activity units and T = the instream temperature, °F. This formula evolves from observations by Baumgartner (5) and subsequently by Pomeroy and Bowlus (6) that rate of sulfide generation in sewers increases about 3.9% per degree F rise in temperature between limits of 60° F to 100° F. The extreme range in this demonstration was 76° F to 89° F.

In this demonstration, the determination of total dissolved sulfides is based on measured pH, absolute $MV \overline{S^{=}}$ and temperature. The program (for the IBM 1130) to compute total dissolved sulfides for this input is described in Appendix A.

SECTION V

RESULTS

TEST STATIONS

Recapping briefly, Stations 1, 13, 6 and 40 are the key downstream sampling stations, listed in order of progression upstream from the downstream terminal as previously shown in Figures 1 and 2. Station 1, the downstream terminal is approximately 835 ft downstream of the air-lift aerator at Station 2. Station 2 is located 525 ft downstream of Station 13 and 185 ft downstream of the intercept of the sewer from Station 13 and an untreated sewer of roughly equal flow. Station 13 is 1500 ft downstream of the U-tube aerator at Station 5. Station 6 is 370 ft downstream of Station 5. Station 40 is the wet well of the lift station pumping to Station 5 through 3000 ft of 12 in. force main and is 400 ft downstream of the U-tube at Station 7. The U-tube at Station 7 is installed on the discharge end of 2050 ft of 10 in. force main. Stations 2, 5B and 7B did not exist prior to the installation of the aeration devices. Station 2 is the air-lift aerator. Stations 5B and 7B are pressure taps in the force mains immediately upstream of the U-tube Venturi aspirators located at Stations 5 and 7. No readings were made at Station 5 before installation of the aeration devices because of extreme turbulence and complaints of odor from residents in the vicinity. Station 6, 370 ft downstream from 5 with nominal velocities and no turbulence is the sampling station selected to evaluate the performance of the U-tube installed at Station 5. Measurements had to be taken at Station 7A, the discharge manhole at Station 7, both before and after activation of the U-tube despite the fact that this manhole had considerable turbulence before installation of the U-tube and contained upwards of 30% unaerated sewage after activation of the U-tube. This was because velocities in the one downstream manhole between Stations 7 and 40 were found to exceed 5 FPS and made sampling and instream measurements impossible.

RAINFALL AND TEMPERATURE BACKGROUND

Figure 13 is an hourly plot of maximum and minimum instream and air temperatures over the test period. Minimum

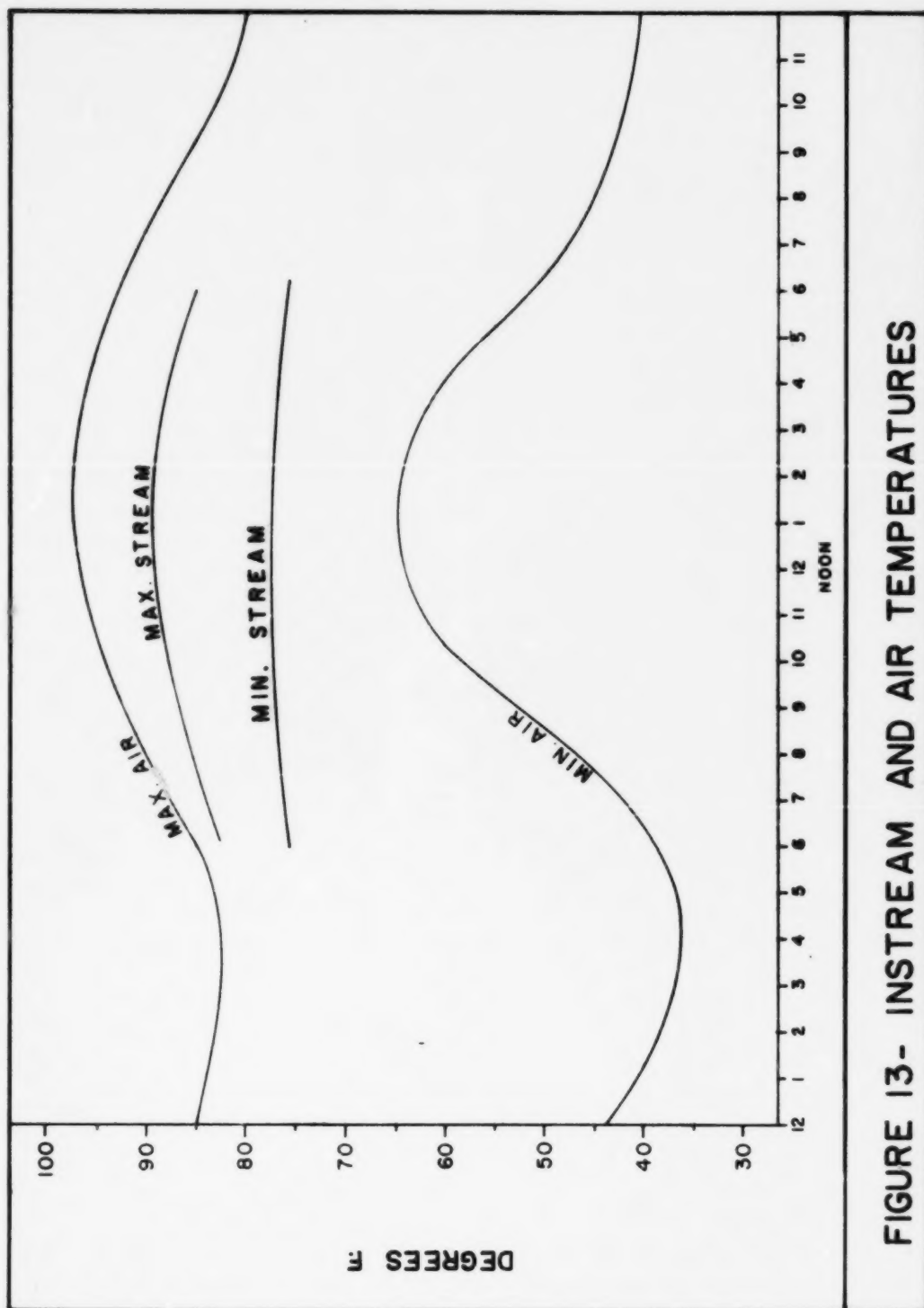


FIGURE 13- INSTREAM AND AIR TEMPERATURES

temperatures were generated entirely in the last two days of the project and relate only to measurements taken at Station 1 on November 5th and 6th. These are the only days during the test period when instream temperatures below 80° F were recorded. Tests were terminated when instream temperatures dropped to 76° F on November 6th. Figure 14 is a daily plot of rainfall and resulting system dilution during the test period.

The curve from Figure 14 is included as an approximate indication of the percent dilution on all daily plots of sulfides, D.O., BOD₅ and COD. The dry weather flow to the plant averages 5.5 MGD. Daily flows significantly above 5.5 are the result of rainwater infiltration. The bar graph on Figure 14 gives the daily occurrence and duration but not the intensity of significant rains during the test period. The curve on Figure 14 represents the totalized daily flow to the treatment plant. Maximum pumping capacity at the treatment plant is slightly in excess of 10 MGD. Normal or dryweather flow is about 4 MGD for 24 hrs but at a rate of about 5.5 MGD during test hours. A plot of 10 MGD, therefore, indicates continuous pumping at maximum capacity for the entire 24-hour period and a dilution of 150%. At anything above 7 MGD the entire system would be heavily surcharged and no instream measurements or sampling would be attempted. Samples and measurements were generally taken only when flow in the system was near normal with gravity sewers not significantly more than half full. It is obvious, however, from the amount of rain encountered throughout the test period that some degree of residual dilution figures in a good percentage of the measurements. The effect, both immediate and residual, of rainwater dilution is apparent in a tendency of the various parameters to track the dilution trace.

ANALYTICAL TESTING

One thousand eighty-nine (1,089) instream measurements were made at the seven test stations over the period July 2, 1970 to August 7, 1970 before activation of the aeration devices. On August 8, 1970, aeration devices were activated at aerator installations, Stations 2, 5, 7 and 31. Subsequently, twelve-hundred thirty-six (1,236) instream measurements were made at nine stations over the period August 11 to November 6, 1970. A tabulation of all

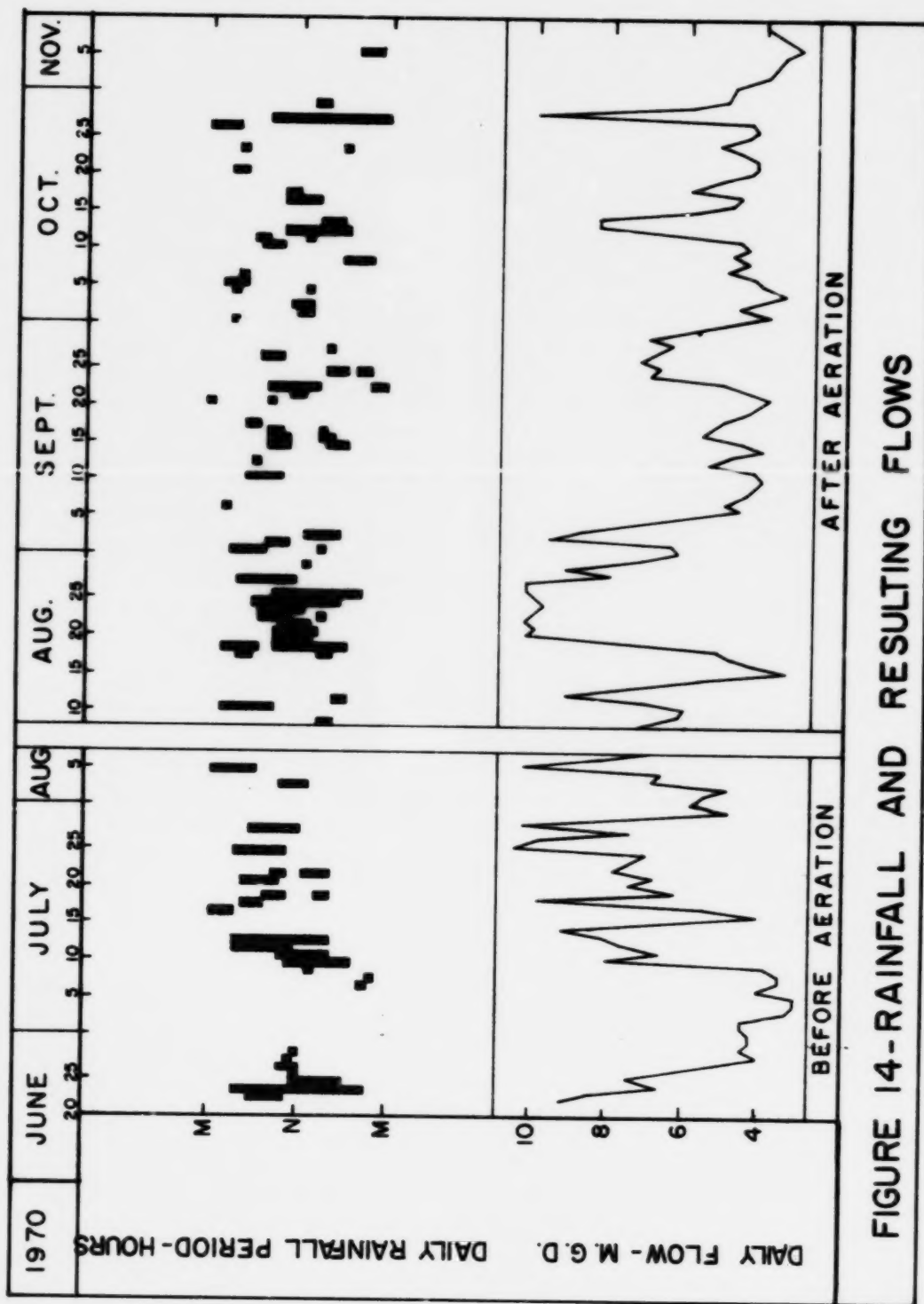


FIGURE 14-RAINFALL AND RESULTING FLOWS

instream readings is included as Appendix B to this report. To give meaningful results, all instream sulfide measurements used in the plots and tabulations have been standardized to 85° F as previously described.

AIRLIFT AERATOR

Station 1 is the downstream terminal of this demonstration and reflects both the performances of the airlift aerator installed at Station 2 and the cumulative effect of all upstream aeration devices. 93% of the flow through Station 1 is from the airlift aerator at Station 2 and 37% of the flow had additionally been through the U-tube at Station 5. Figure 15 is a daily plot of D.O. at Station 1, the downstream terminal. No measureable D.O. was recorded at this station before activation of the aeration devices. After the aeration devices were activated, a residual D.O. was always evident ranging from a low of 0.2 mg/l to a high of 3.8 mg/l and averaging 1.4 mg/l.

Figure 16 is the daily plot of sulfides at Station 1. Dissolved sulfides (S_{85}) were consistently present at Station 1 before activation of the aeration devices, ranging from a low of 0.03 mg/l to a high of 3.45 mg/l, and averaging 0.63 mg/l. After activation of the aeration devices 40 measurements were made. Only three of the 40 measurements showed traces of sulfide (.01 mg/l, .04 mg/l and .09 mg/l). In the remaining 37 measurements no sulfide was detected.

Figure 17 is the hourly plot of 69 dissolved sulfide measurements taken at Station 1 (29 before and 40 after activation of aeration devices). Figure 18 is the daily plot of BOD₅ and COD run on samples taken at the same time sulfides were measured at Station 1. Before activation of the aeration devices, BOD₅ ranged from a low of 48 mg/l to a high of 334 mg/l with an average of 169 mg/l. COD ranged from a low of 158 mg/l to a high of 554 mg/l with an average of 310 mg/l. After activation of the aeration devices BOD₅ ranged from a low of 42 mg/l to a high of 281 mg/l with an average of 128 mg/l and COD ranged from a low of 117 mg/l to a high of 304 mg/l with an average of 208 mg/l. The indicated reduction attributable to in-line aeration was 100% for dissolved sulfides, 24% for BOD₅ and 33% for COD.

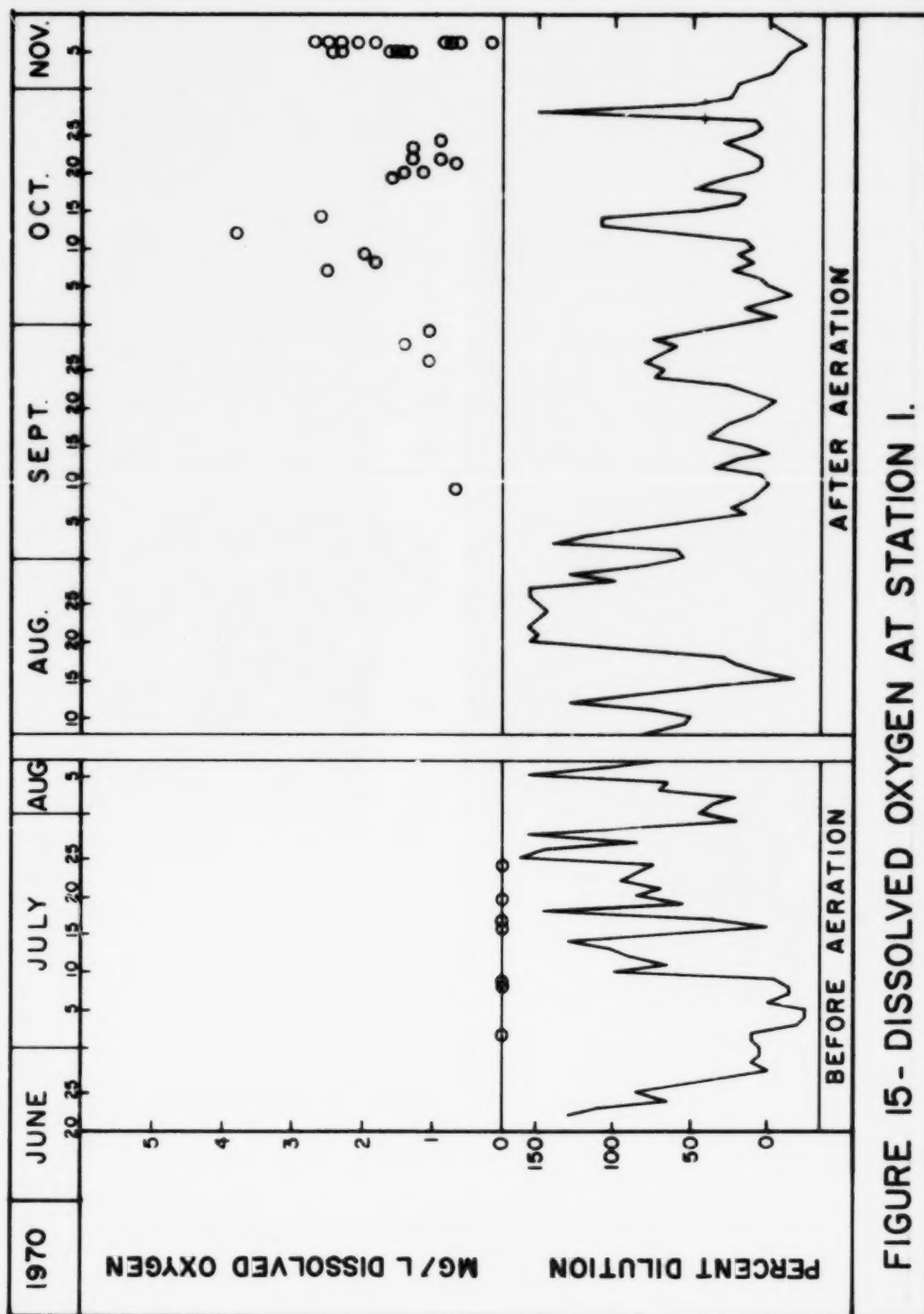


FIGURE 15 - DISSOLVED OXYGEN AT STATION 1.

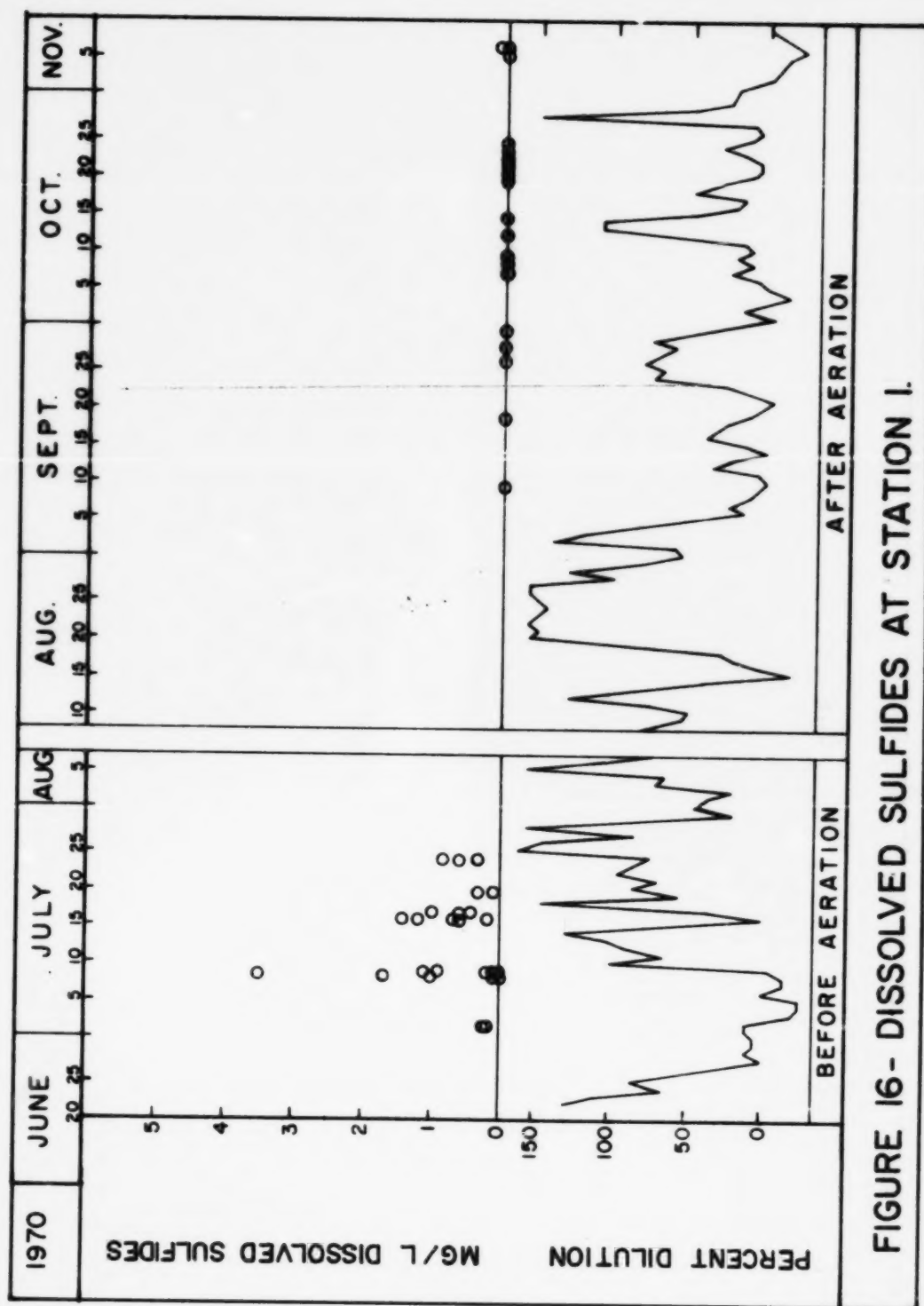


FIGURE 16- DISSOLVED SULFIDES AT STATION 1.

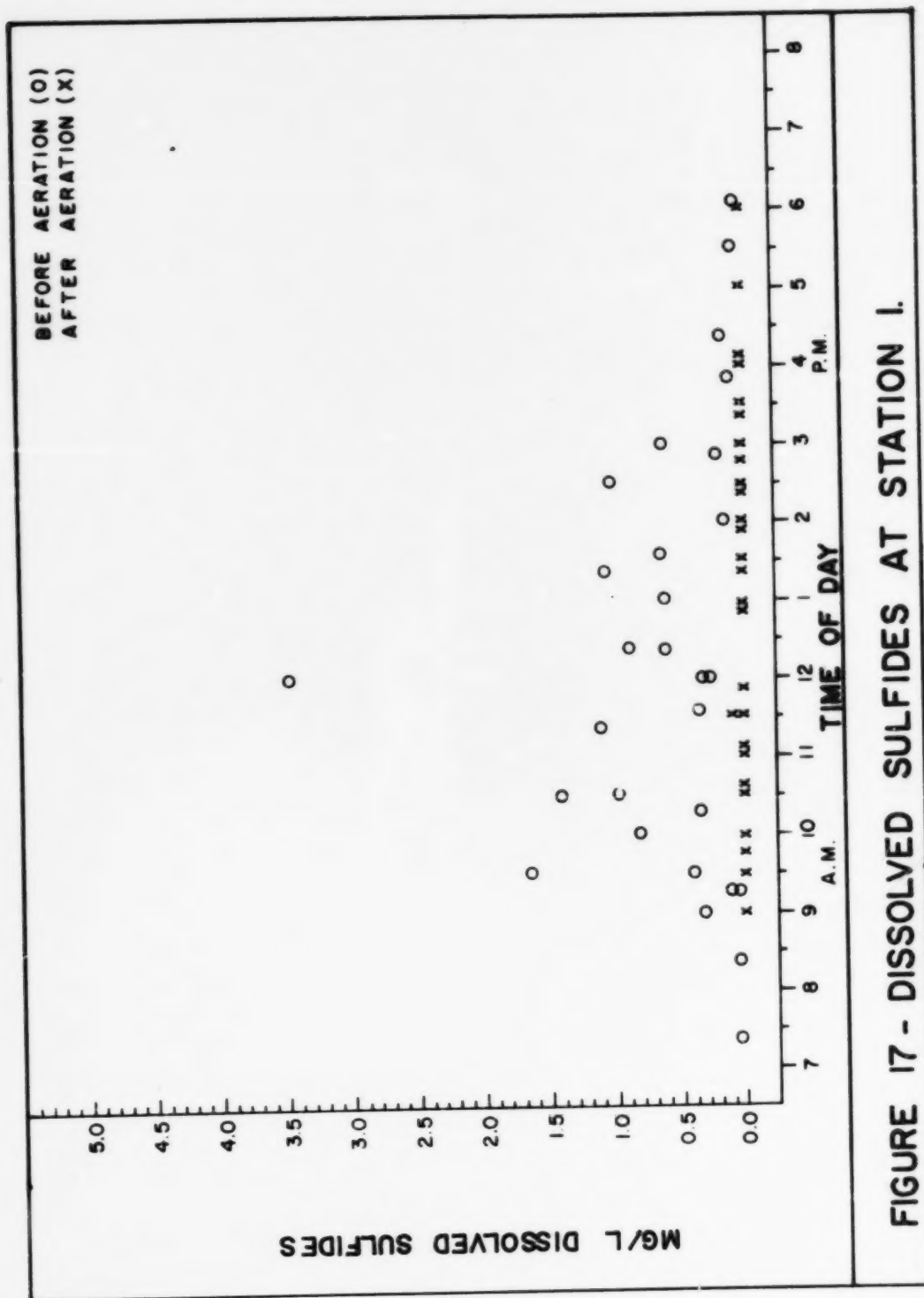


FIGURE 17 - DISSOLVED SULFIDES AT STATION I.

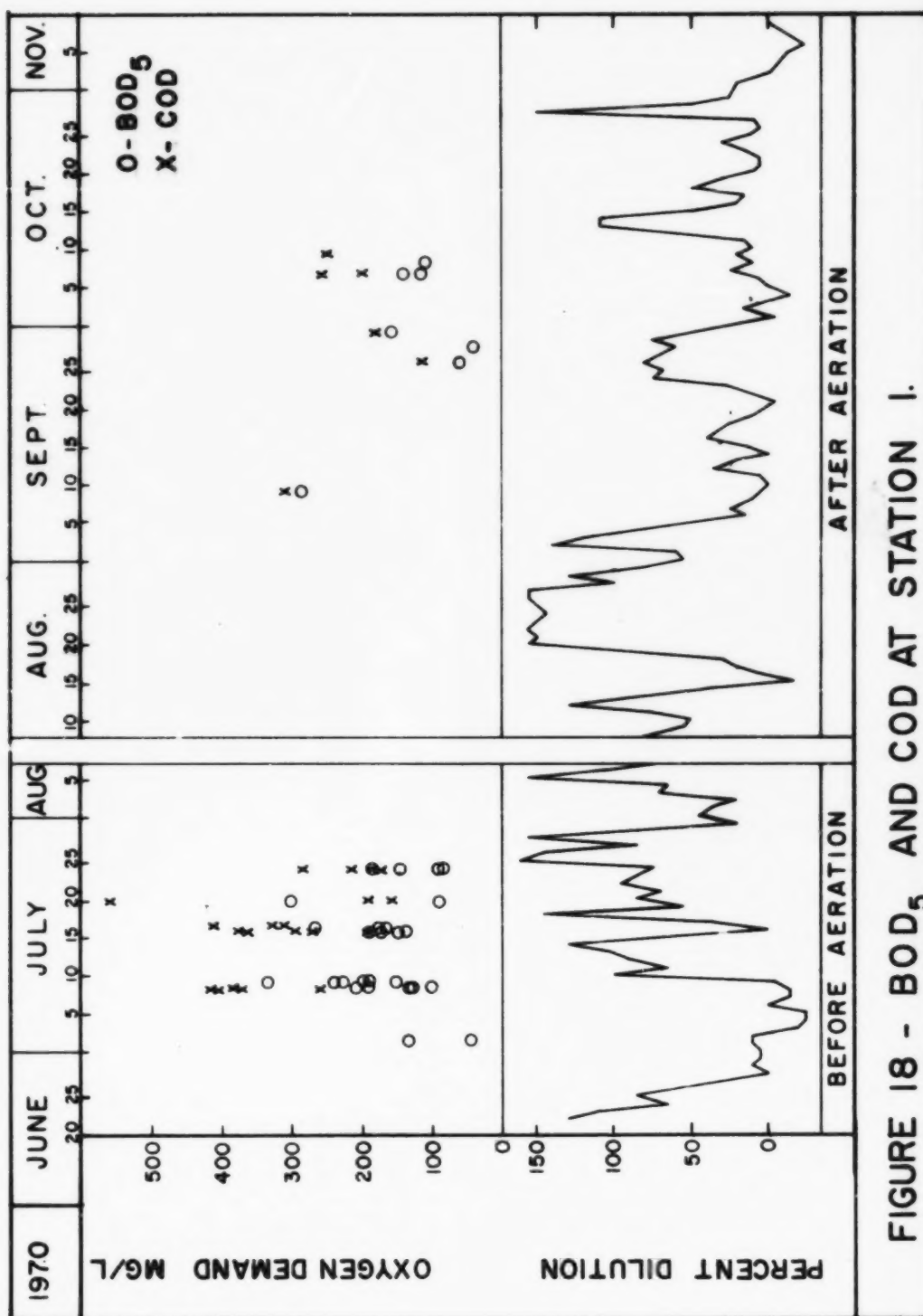


FIGURE 18 - BOD₅ AND COD AT STATION 1.

U-TUBE EVALUATION

Station 13 is a manhole 1500 ft downstream of the discharge of the U-tube at Station 5. 79% of the flow through Station 13 is from the U-tube at Station 5 and the remainder from untreated gravity laterals. Figure 19 is the daily plot of D.O. at Station 13 before and after activation of the aeration devices. Before activation of the aeration devices, 15 of 23 D.O. measurements registered 0. The highest D.O. recorded was 0.4 mg/l and the average of the 23 measurements was 0.01 mg/l. After activation of the aeration only two of twenty-seven D.O. measurements registered 0. The highest D.O. was 2.1 mg/l and the average of the 27 D.O. measurements was 0.7 mg/l. Figure 20 is the daily plot of dissolved sulfides (S_{85}) at Station 13. Before activation of the aeration devices, in only one of 24 measurements was there no detectable sulfides. Dissolved sulfides ranged from this one zero measurement to a high of 1.3 mg/l with an average of 0.30 mg/l. After activation of the aeration devices there was no measurable sulfides in 16 of 24 measurements. There was one reading of 0.23 mg/l, all other measurements were below 0.10 PPM and the average of the 24 measurements was 0.02 mg/l dissolved sulfides (S_{85}). The apparent reduction in dissolved sulfides at Station 13 attributable to aeration was 93%. Figure 21 is the hourly plot of 48 sulfide measurements at Station 13 (24 before and 24 after activation of the U-tube at Station 5). Figure 22 is the daily plot of BOD₅ and COD at Station 13 run on samples taken at the same time sulfide measurements were made. Before activation of the aeration devices BOD₅ ranged from a low of 53 mg/l to a high of 458 mg/l with an average of 176 mg/l. COD ranged from a low of 96 mg/l to a high of 634 mg/l with an average of 315 mg/l. After activation of the aeration devices BOD₅ ranged from a low of 36 mg/l to a high of 308 mg/l with an average of 150 mg/l. COD ranged from a low of 161 mg/l to a high of 408 mg/l with an average of 250 mg/l. Based on the average values, the apparent reduction attributable to aeration was 21% for COD and 15% for BOD₅.

Station 6 is the first manhole 370 ft downstream of the discharge of the U-tube at Station 5. Based on measurements at time of sampling, the fraction of aerated sewage through this station averaged 96%. Figure 23 is the plot

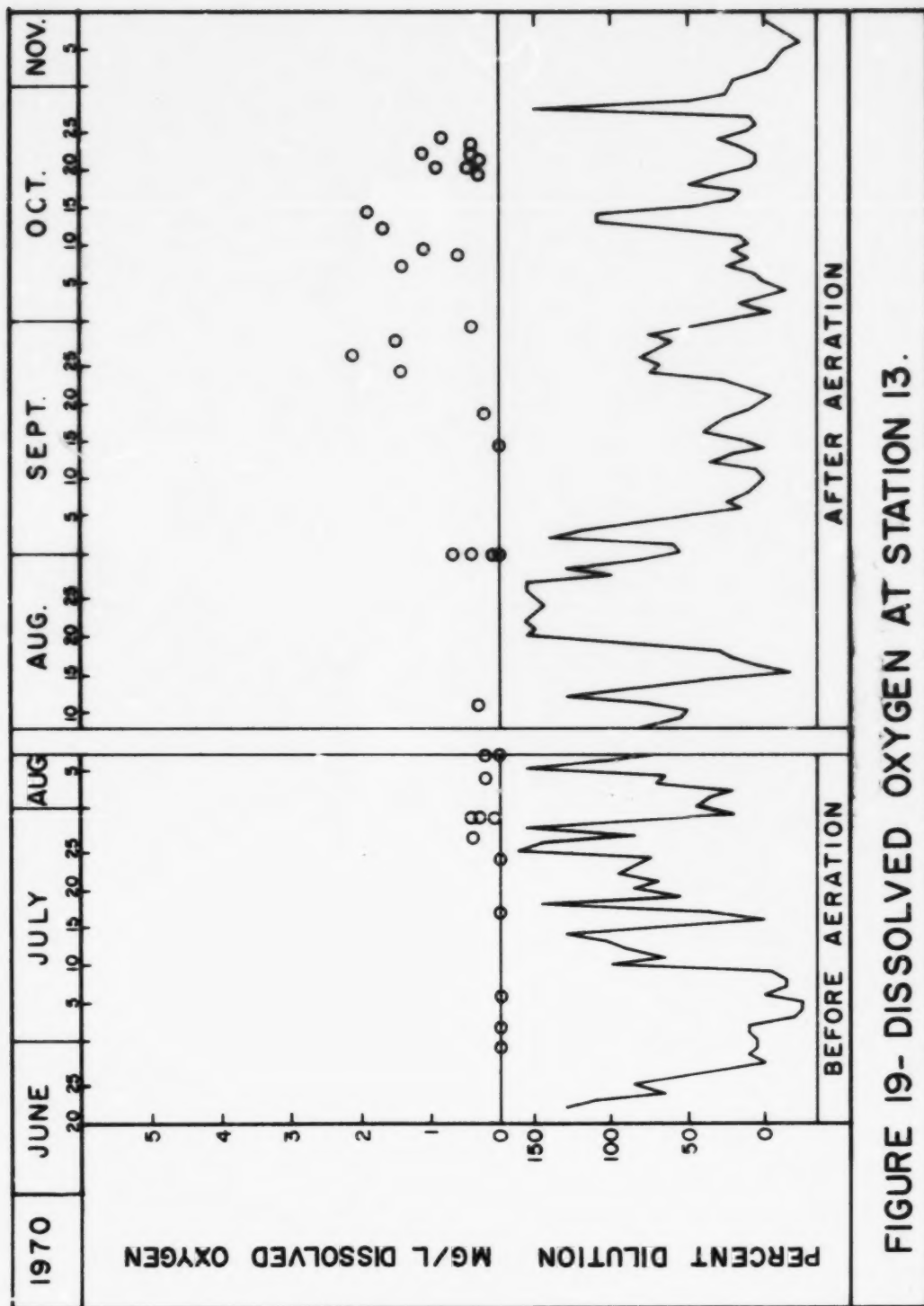


FIGURE 19- DISSOLVED OXYGEN AT STATION 13.

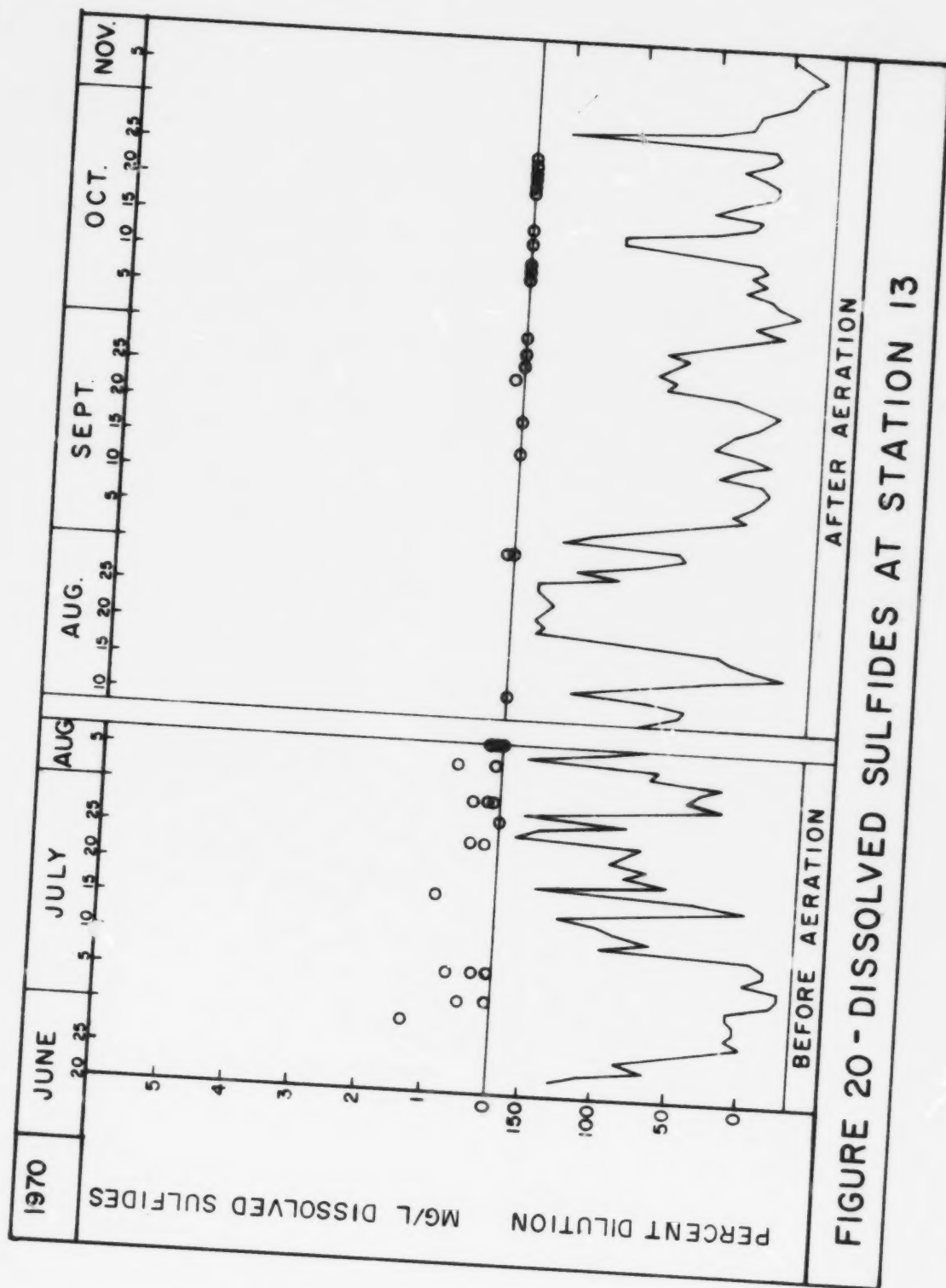


FIGURE 20 - DISSOLVED SULFIDES AT STATION 13

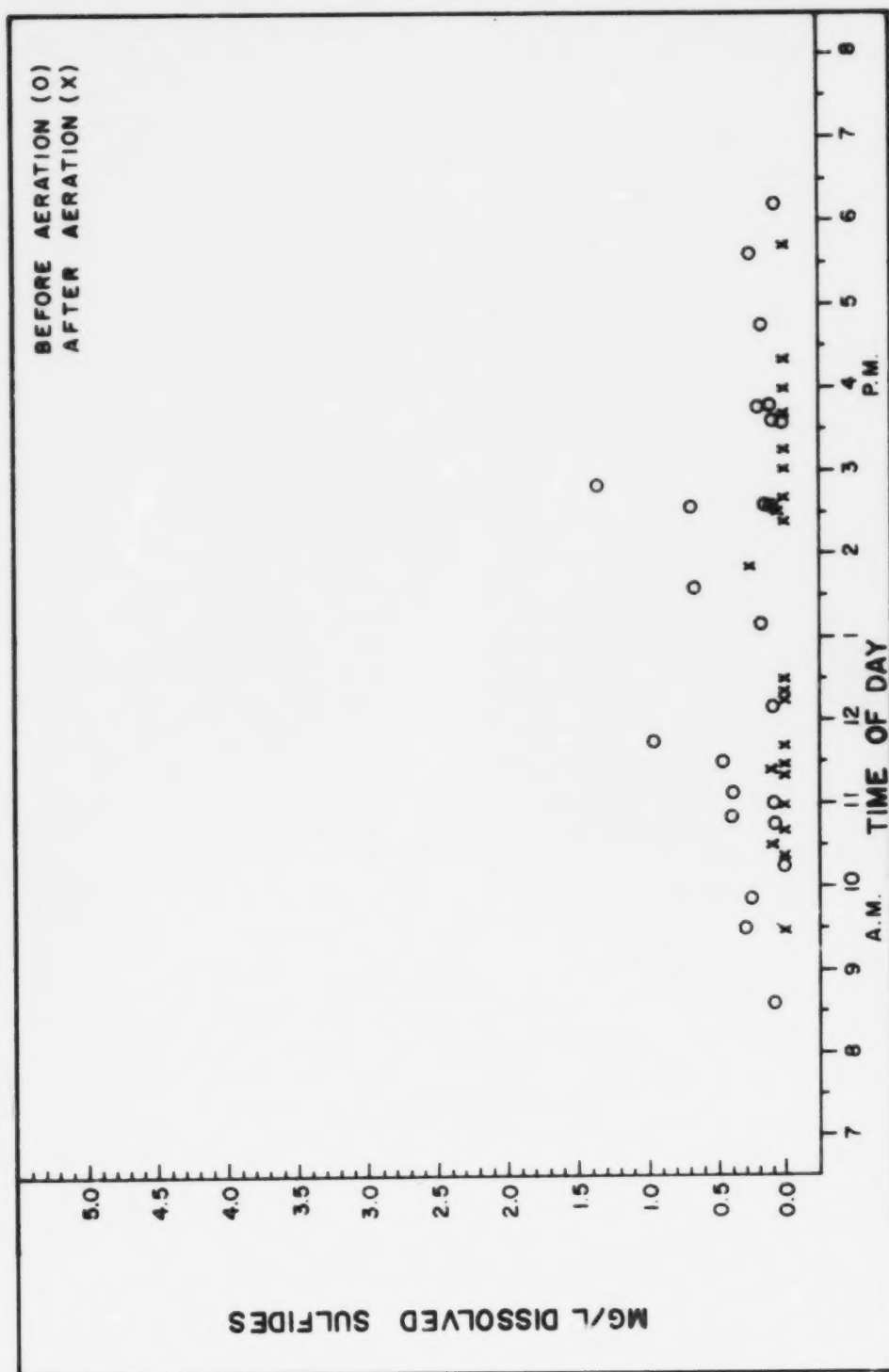


FIGURE 21- DISSOLVED SULFIDES AT STATION 13.

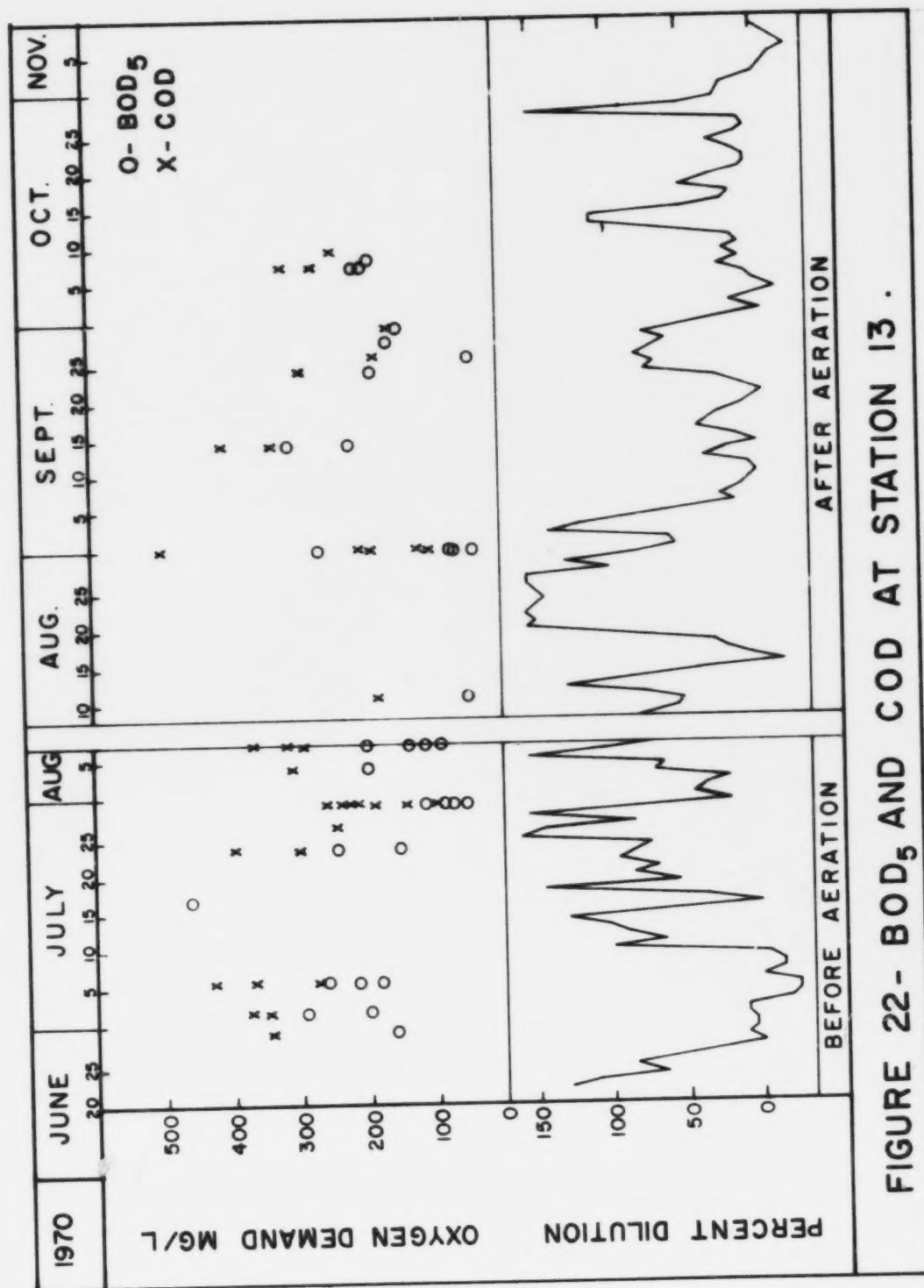


FIGURE 22- BOD₅ AND COD AT STATION 13 .

D.O. measurements recorded at Station 6 before and after activation of the aeration devices. The aeration resulting from the seven foot fall from the force main into Station 5 before installation of the U-tube is clearly evident. Only five of thirty-two measurements showed no D.O. The high was 2.1 mg/l and the average of 32 measurements was 0.8 mg/l. After installation of the U-tube which eliminated the seven foot fall, D.O. at Station 6 ranged from a low of 0.6 mg/l to a high of 2.8 mg/l with an average of 1.6 mg/l. Figure 24 is the daily plot of dissolved sulfides at Station 6 before and after activation of the aeration devices. Before activation of the aeration devices only three of thirty-two measurements showed no measureable sulfides. The high of 6.0 mg/l was the highest concentration of dissolved sulfides recorded in the demonstration. The average of the 32 measurements was 0.51 mg/l dissolved sulfides. After activation of the aeration devices, dissolved sulfides at Station 6 ranged from zero to a high of 0.18 mg/l with an average of 0.05 mg/l. The apparent reduction in dissolved sulfides (S_{85}) attributable to aeration was 90%. Figure 25 is the hourly plot of 41 measurements of dissolved sulfides. Figure 26 is the daily plot of BOD_5 and COD run on samples taken at the same time sulfide measurements were made, before and after activation of the aeration devices at Station 6. Before activation of the aeration devices, BOD_5 ranged from a low of 33 mg/l to a high of 285 mg/l with an average of 151 mg/l. COD ranged from a low of 75 mg/l to a high of 539 mg/l with an average 296 mg/l. After activation of the aeration devices, BOD_5 ranged from a low of 28 mg/l to a high of 294 mg/l with an average of 128 mg/l and COD ranged from a low of 123 to a high of 529 mg/l with an average of 260 mg/l. The apparent reduction at Station 6 attributable to aeration was 12% for COD and 17% in BOD .

Station 5 is the location of the larger of two Venturi aspirated U-tubes. Before installation of the U-tube, a 12 in. force main discharged into the manhole, designated 5A in Figure 2, with a seven foot fall from the invert of this force main to the invert of the receiving 21" gravity sewer. 2400 ft of 8 in. gravity sewer with its invert set 0.4 feet above the invert of the 21 in. sewer also discharges into 5A. The invert of the 12 in. U-tube discharge was set 0.1 feet above the invert of the receiving sewer, consequently with the activation of the U-tube, the seven foot fall of the force main discharge

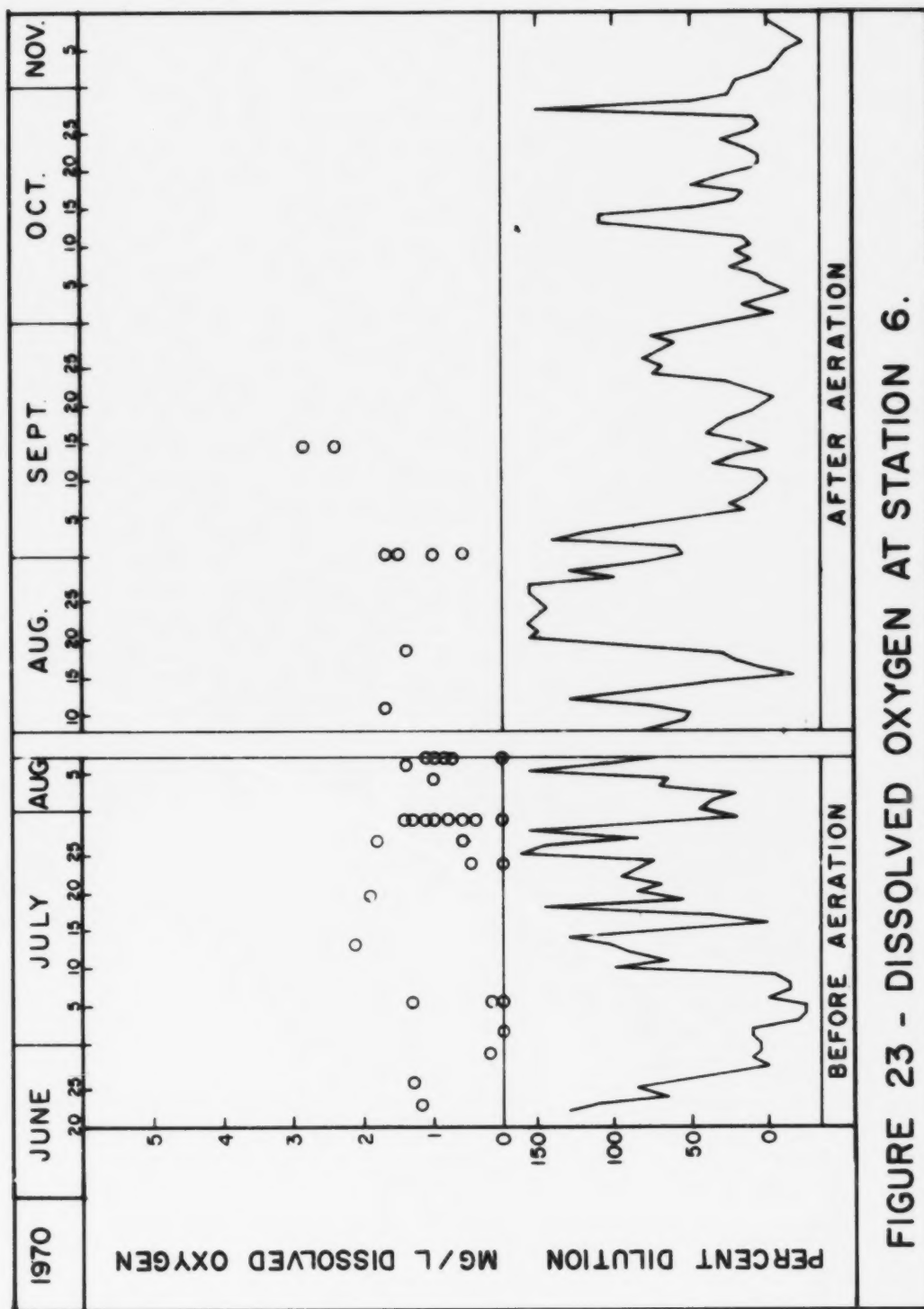


FIGURE 23 - DISSOLVED OXYGEN AT STATION 6.

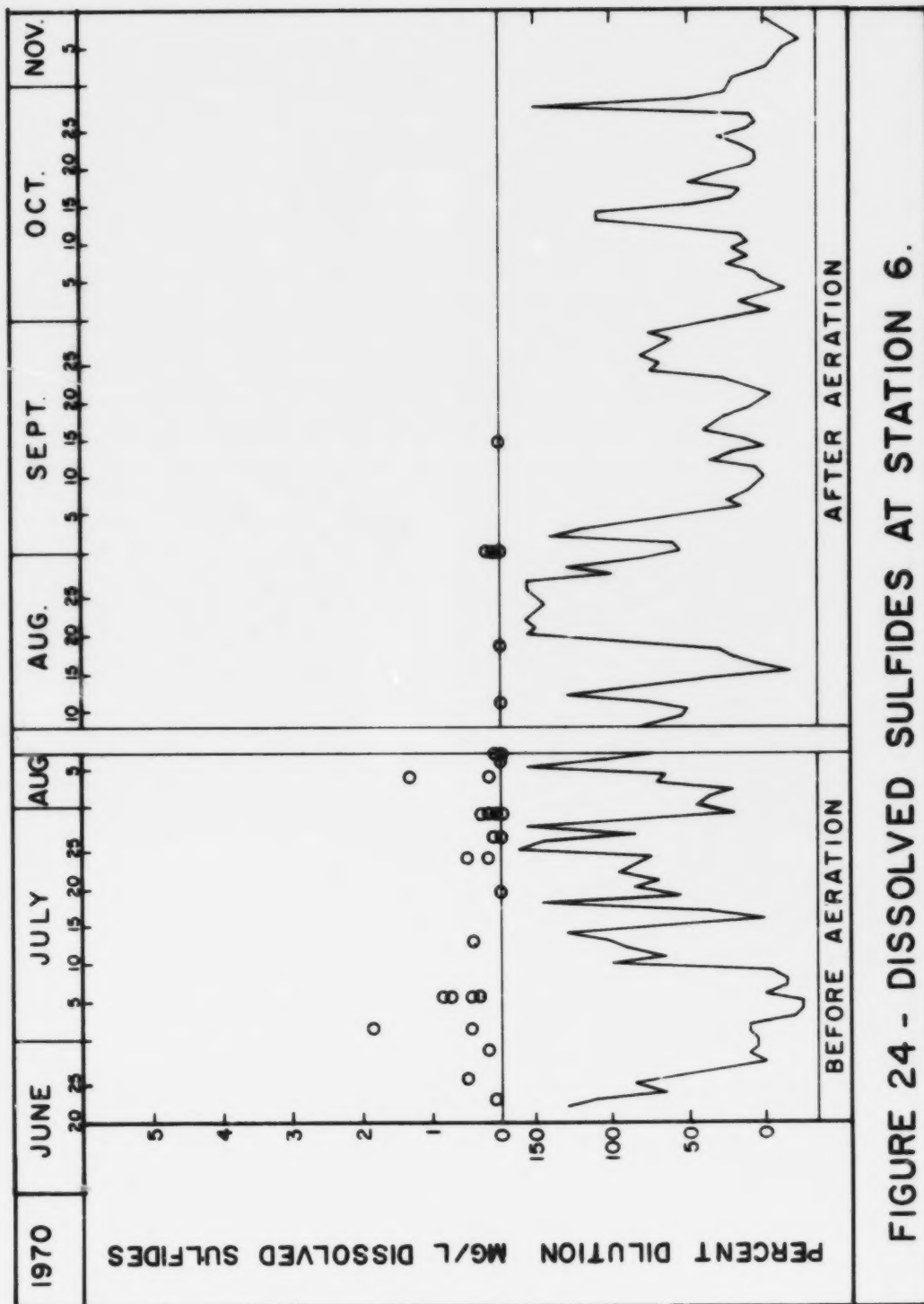


FIGURE 24 - DISSOLVED SULFIDES AT STATION 6.

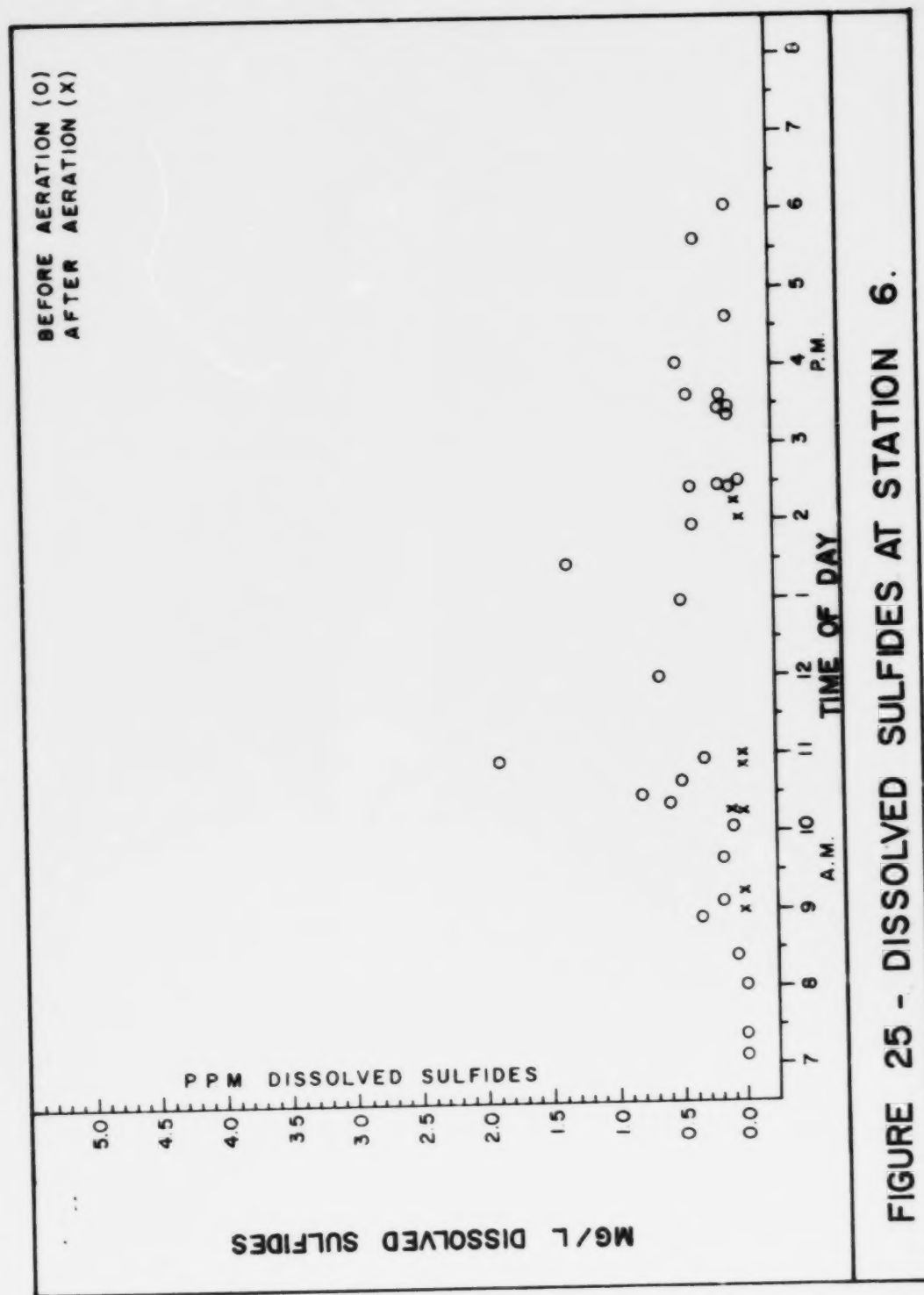


FIGURE 25 - DISSOLVED SULFIDES AT STATION 6.

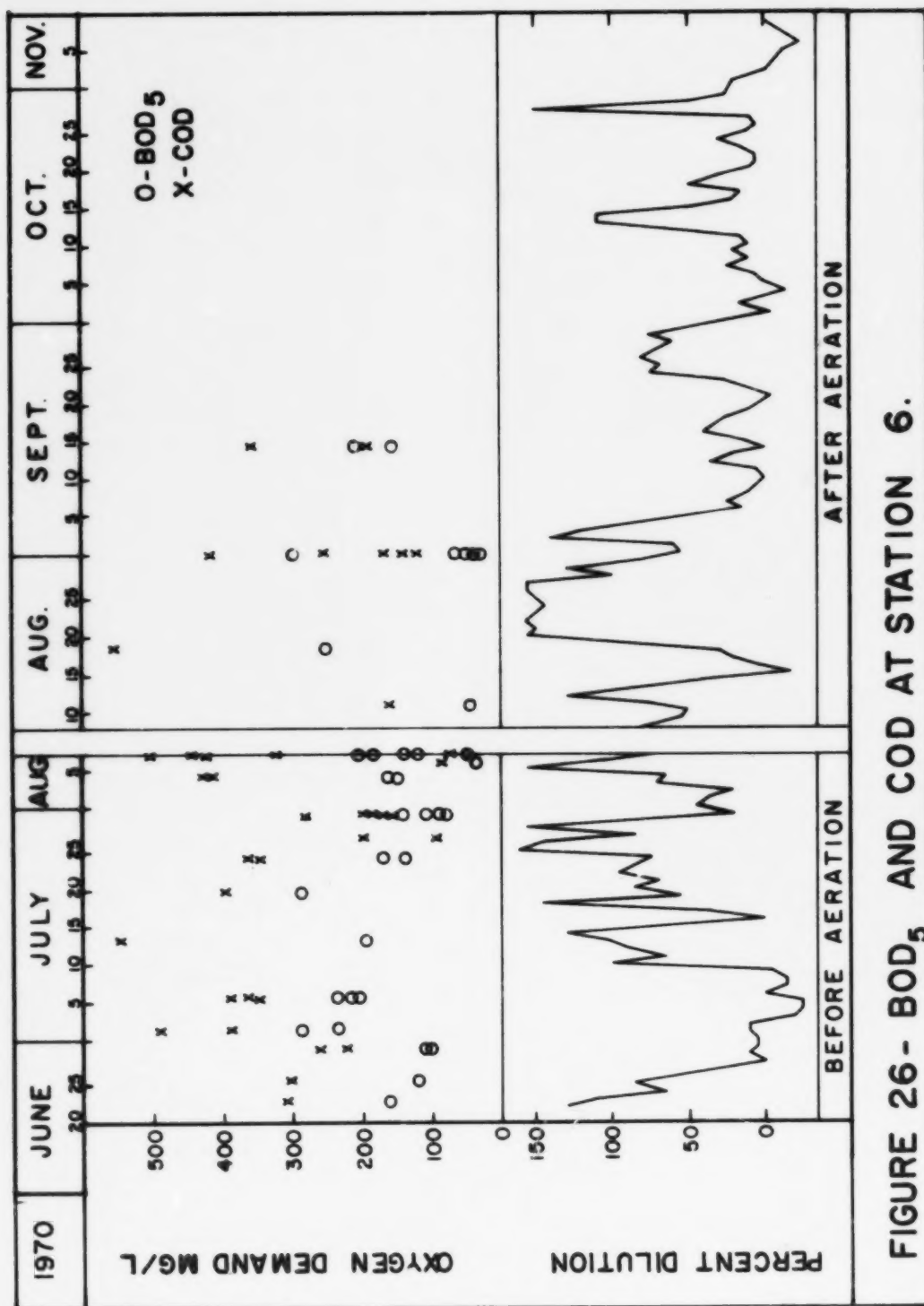


FIGURE 26- BOD₅ AND COD AT STATION 6.

and resulting extreme turbulence at Station 5A were completely eliminated. The flow in the 8 in. gravity sewer during sampling was consistently at or just below a half pipe indicating a relatively steady contribution of about 100 GPM. The flow through the U-tube averaged around 1400 GPM with an aspiration of 15 CFM for an air/water volume ratio of 0.08. Oxygen transfer averaged 5.1 mg/l from an average initial demand (IOD) of 2.5 mg/l to an average residual D.O. of 2.6 mg/l. Table 1 is a tabulation of 13 sets of measurements taken at 5B, a tap immediately upstream of the Venturi, and in 5A the manhole receiving the combined discharges of the U-tube and the untreated 8 in. gravity sewer. Flow through the U-tube accounted for 96% of the combined discharges. The data in Table 1 reflects the original entrance elbow configuration of the U-tube as shown in Figure 8 and consequently relates to sulfide, D.O., BOD₅ and COD data at Stations 6, 13 and 1.

Table 2 is a tabulation of data taken after final modification of the entrance elbow as shown in Figure 9. There is no indication that oxygen transfer in the U-tube was increased by this modification, however, there was one significant improvement. With the original configuration, a period of 40 to 50 seconds elapsed between the initial flow of sewage through the Venturi and the start of aspiration. After modification, this lag was reduced to between 10 and 15 seconds. Since the average duration of flow during an operating cycle was about eight minutes, the total aeration per cycle was improved by roughly 7%. Data for various air/water ratios and corresponding head losses are also included in Table 2. Note that the upstream head measured immediately upstream of the Venturi is negative when aspiration is closed off or throttled. Under these conditions the capacity of the lift station is actually increased by the installation of the U-tube. It is apparent from this data that optimum oxygen transfer with natural aspiration occurs with flows above 1900 GPM, however, a 3 to 4 ft increase in head loss results. Supercharging to obtain higher air/water ratios resulted in drastically increased head losses without a corresponding gain in oxygen transfer. There appears to be about 120 GPM or an 8% reduction in pump capacity from the installation of the U-tube at this station for normal one pump operation. For two pumps there appeared to be a loss in capacity on the order of 300 GPM or 12%. This reduction in capacity

TABLE I

IOD AT STATION 5B, UPSTREAM
OF THE VENTURI AND DO IN 5A
RECEIVING THE U-TUBE DISCHARGE

Date ----	Sta. 5B IOD mg/l	Sta. 5A DO mg/l	Transfer mg/l O ₂
10/1/70	1.3	2.4	3.7
10/7/70	1.0	3.6	4.6
10/7/70	2.2	2.8	4.9
10/12/70	2.3	2.8	5.1
10/14/70	-0.5	4.1	3.6
10/19/70	2.0	2.9	4.9
10/20/70	3.9	1.9	5.8
10/20/70	3.9	1.9	5.8
10/21/70	2.0	1.6	3.6
10/22/70	4.3	2.0	6.3
10/22/70	3.1	2.8	5.9
10/23/70	3.9	2.2	6.1
10/24/70	2.6	2.6	5.2
Average	2.5	2.6	5.1

Air/Water Volume Ratio 0.07

TABLE 2 TABULATIONS OF VARYING SEWAGE
AND ASPIRATION RATES AND THE
EFFECT ON TOTAL OXYGEN TRANSFER &
HEAD LOSS IN THE U-TUBE AT STATION 5

Water Flowrate (GPM)	Air Flowrate (CFM)	Air/Water Volume Ratio	Upstream Head (FT H ₂ O)	Total Oxygen Transfer (MG/L)
1570(1)	0	--	-4.75	---
2060(2)	0	--	-5.08	---
2000(2)	5.5(3)	0.021	-3.75	1.1
2180(2)	10.5(3)	0.036	-2.75	2.4
1580(1)	7.5(3)	0.036	-5.25	3.3
2180(2)	16.0(3)	0.055	-0.98	3.5
2090(2)	17.0(3)	0.061	-0.92	4.7
2090(2)	20.0(3)	0.071	-0.60	4.7
1340(1)	14.0	0.078	3.50	4.5
1400(1)	15.0	0.080	3.83	4.9
1960(2)	28.0	0.107	7.50	6.4
1920(2)	28.0	0.109	7.08	6.5
1280(2)	20.0(4)	0.120	20.83	7.7
900(1)	19.0(4)	0.158	17.25	7.9
1620(2)	40.0(4)	0.185	28.60	9.1
1620(2)	60.0(4)	0.277	29.17	8.9

- (1) One pump)
 (2) Two pumps) Lift Station 40
 (3) Aspiration Air Throttled
 (4) Supercharging with Compressor

can be entirely eliminated by limiting (throttling) the aspiration air but with some reduction in oxygen transfer. Data from Station 5 indicates that U-tube design can generally be adapted to existing pumps even when little or no reserve pump capacity exists providing dissolved sulfides are below 2 mg/l. When a higher concentration of dissolved sulfides make optimum oxygen transfer desirable, it may be necessary to change the pump impellers or possibly pumps and motors to accommodate the higher head loss.

Table 3 is a tabulation of dissolved sulfides (S_{85}) and D.O. taken at Station 5 after activation and before modification of the entrance elbow for the U-tube. It will be noted that no D.O. was found in any sample from 5B, the tap in the force main immediately upstream of the Venturi. Immediate oxygen demand (IOD) was not run on these samples. The residual D.O. measured in 5A, the manhole receiving the U-tube discharge correlates very well with the data tabulated in Table 1 when IOD was measured in the samples from 5B. In contrasting the samples from 5B with those of 5A in both Tables 1 and 3, it must be realized that the measurements do not relate to the same slug of sewage. It was not possible to make the two measurements within the approximately 30 second interval of travel between points 5B and 5A. The pairs of measurements in 5B and 5A were in all cases taken during the same operating cycle and the average values are considered significant. The data from Table 3 confirms that the oxidation of sulfides is only partially completed in the U-tube. The reduction in dissolved sulfides from Station 5B to 5A based on the average values of .15 mg/l and .06 mg/l respectively is on the order of 60% with a high average D.O. (2.3 mg/l) persisting in Station 5A. This contrasts to a 90% reduction at Station 6, only 370 ft downstream, and 93% at Station 13, 1450 ft downstream, with no further aeration beyond the air-water interface in the gravity sewer. While obviously there is some oxygen enrichment of the sewer atmosphere as entrained air leaves the stream, this occurs in the first few feet when residual D.O. in the stream is highest and the continuing oxidation of sulfides in the gravity sewer appears largely, if not entirely, the result of D.O. imparted to the stream in the U-tube.

Station 40 is one of dual wet wells of the pump station pumping to the U-tube at Station 5. Station 40 receives the 18 in. gravity sewer carrying the discharge from the

TABLE 3

TABULATION OF DISSOLVED SULFIDES AND
DISSOLVED OXYGEN AT STATIONS 5B
(UPSTREAM OF THE VENTURI) AND 5A (THE
MANHOLE RECEIVING THE U-TUBE DISCHARGE)

Date	Time	5B		5A	
		mg/l S ₈₅	mg/l DO	mg/l S ₈₅	mg/l DO
08/18/70	1010	0.06	0	0.05	2.8
08/31/70	0845	0.07	0	0.04	1.8
08/31/70	0945	0.14	0	0.08	0.1
08/31/70	1045	0.14	0	0.06	1.6
08/31/70	1510	0.31	0	0.21	2.4
09/08/70	1120	0.07	0	0.05	2.3
09/09/70	1000	0.13	0	0.15	1.3
09/18/70	1645	0.04	0	0.01	3.6
09/28/70	1435	0.06	0	0.04	3.6
09/30/70	1000	0.17	0	0.06	2.8
10/07/70	1025	0.11	0	0.07	2.7
10/14/70	1450	0.46	0	0.01	4.1
10/19/70	1055	0.31	0	0.00	2.9
10/20/70	1015	0.01	0	0.00	1.9
10/20/70	1500	0.09	0	0.02	1.9
10/21/70	1150	0.04	0	0.01	1.6
10/22/70	1000	0.03	0	0.01	2.0
10/22/70	1445	0.41	0	0.20	2.8
Averages		0.15	0	0.06	2.3

U-tube at Station 7 together with the flow of the 10 in. gravity sewer entering the manhole designated Station 7A. Station 40 is connected to Station 30 by a 24 in. equalizer providing a combined wet well volume of 5,000 gal. Since these two wet wells also receive the combined flow of two 10 in. and one 8 in. gravity sewers in addition to the intermittent discharge of the two aerated force mains, no clear cut significance can apply to any sample. Despite the questionable nature of samples from Station 40 (as discussed earlier, the data obtained related to a sewage flow containing between 40% and 85% aerated sewage). This is the only data indicating the downstream effect of the U-tube at Station 7. Figure 27 is a daily plot of D.O. at Station 40 before and after activation of the aeration devices. Before activation of the aeration devices D.O. ranged from a low of 0.4 mg/l to a high of 3.5 mg/l with an average value of 1.9 mg/l. This high D.O. appears to be the result of high falls from the 10 in. force main into Station 7A (4 ft), the 18 in. gravity into Station 40 (2 ft to 5 ft) and the 8 in. force main into Station 30 (3 ft to 6 ft). After activation of the aeration devices D.O. in Station 40 ranged from a low of 0.3 mg/l to a high of 3.8 mg/l with an average value of 2.3 mg/l. It is significant in comparing data before and after aeration that the U-tube at Station 7 eliminated the four foot fall into 7A with the attendant oxygenation and stripping of a considerable amount of H_2S . The falls into Stations 40 and 30, while altered to ranges of 0 ft to 5 ft and 1 ft to 6 ft, respectively, by raising the high water level to prolong the pump cycle, still existed with substantially the same turbulence, oxygenation and stripping of sulfide as before. Figure 28 is the daily plot of sulfides at Station 40. Before activation of the aeration devices dissolved sulfides (S_{85}) in Station 40 ranged from 0 to a high of 3.91 mg/l with an average value of 0.42 mg/l. After activation of the aeration devices dissolved sulfides (S_{85}) at Station 40 ranged from 0 to a high of 0.32 mg/l with an average value of 0.11 mg/l and an apparent reduction in dissolved sulfides attributable to upstream aeration of 74%. Figure 29 is the hourly plot of dissolved sulfides before and after activation of the aeration devices. Figure 30 is the daily plot of BOD_5 and COD at Station 40. Before activation of the aeration devices, BOD_5 ranged from a low of 21 mg/l to a high of 320 mg/l with an average value of 174 mg/l. COD ranged from a low of 64 mg/l to a high

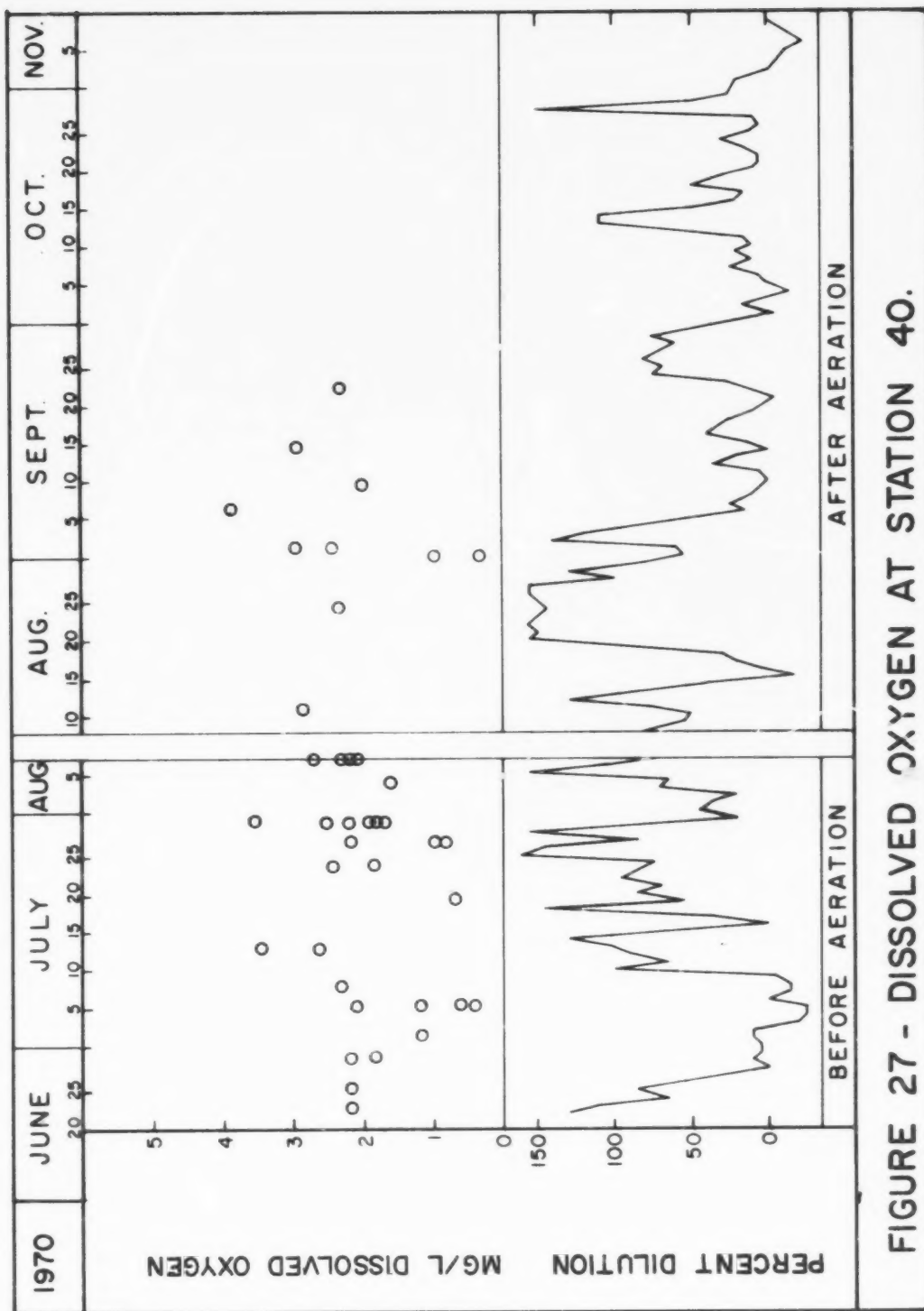


FIGURE 27 - DISSOLVED OXYGEN AT STATION 40.

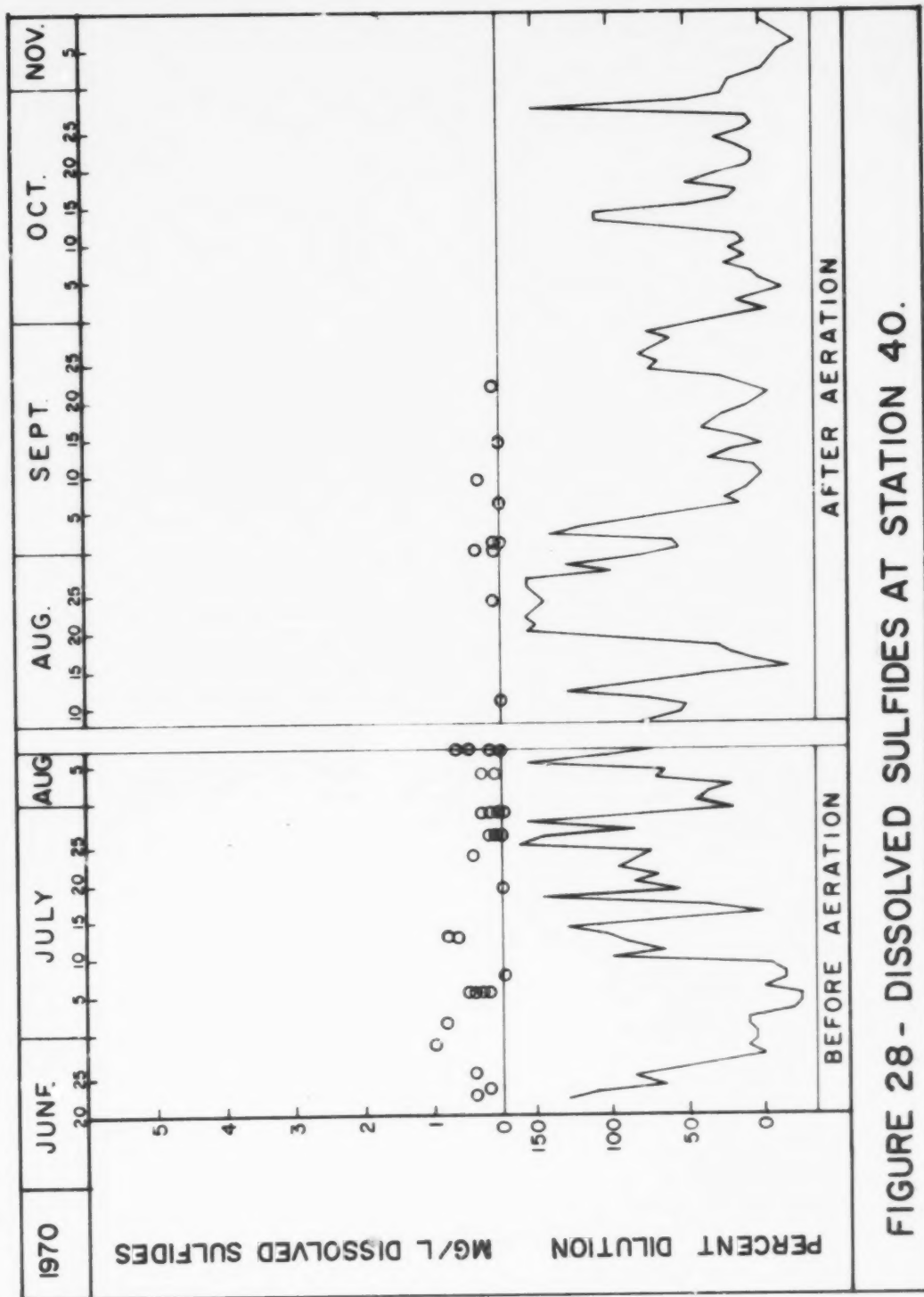


FIGURE 28 - DISSOLVED SULFIDES AT STATION 40.

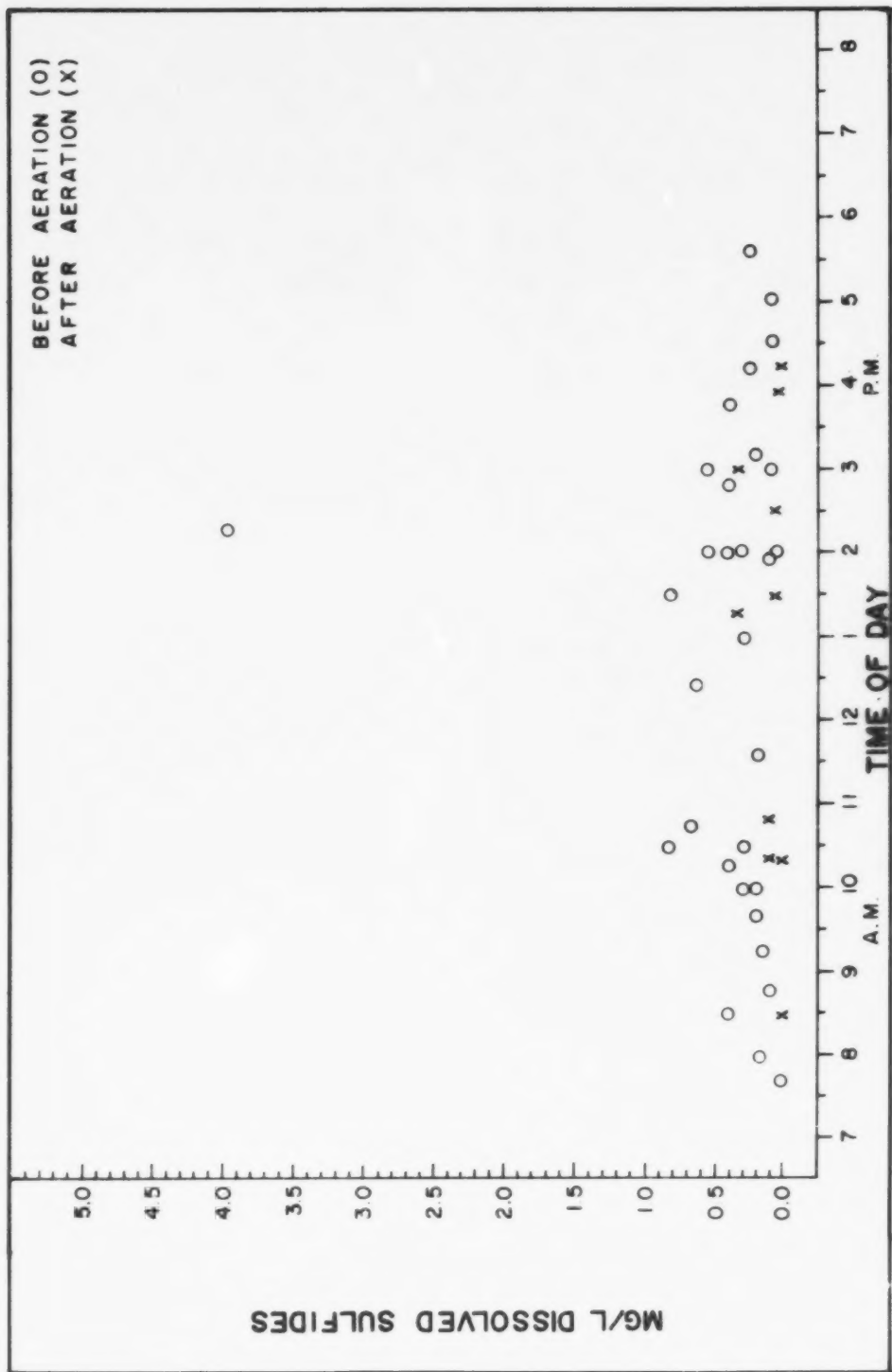


FIGURE 29 - DISSOLVED SULFIDES AT STATION 40.

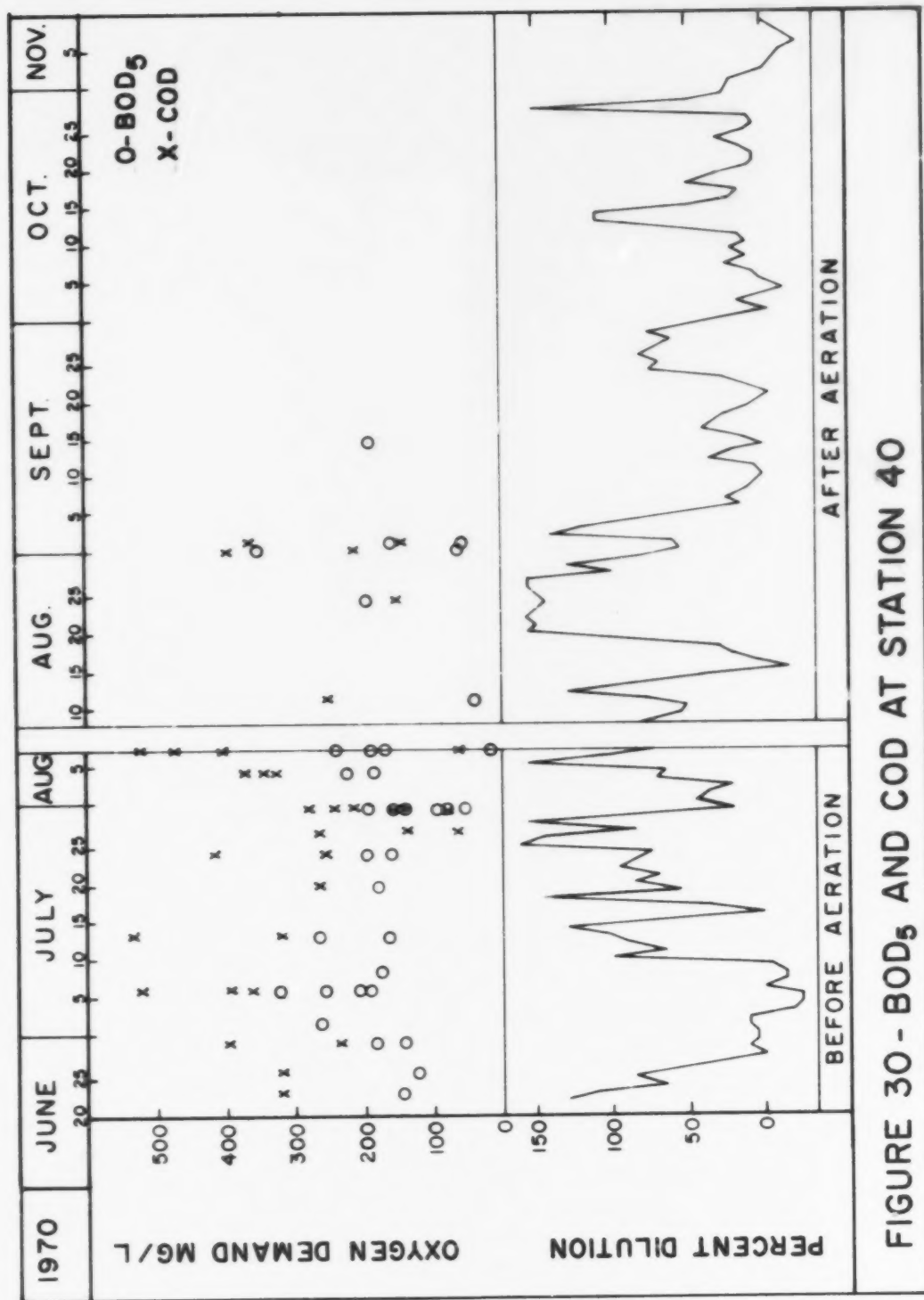


FIGURE 30 - BOD₅ AND COD AT STATION 40

of 528 mg/l with an average value of 306 mg/l. After activation of the aeration devices BOD₅ ranged from a low of 42 mg/l to a high of 351 mg/l with an average value of 152 mg/l. COD ranged from a low of 149 mg/l, a high of 393 mg/l with an average value of 251 mg/l. The apparent reduction attributable to aeration is 13% for BOD₅ and 18% for COD.

Station 7 is the location of the smaller of two U-tubes and is the upstream terminal of the demonstration. The U-tube at Station 7 is installed on the discharge end of 2050 ft of 10 in. force main. The centerline of the Venturi is 30 in. above the centerline of the original discharge. Flow through the U-tube in normal automatic single pump operation with an aspiration of 4 CFM was on the order of 600 GPM. Upstream pressure immediately ahead of the Venturi ranged between 23 and 37 in. H₂O with an average value of 25.2 in. H₂O. With no aspiration, flow increased to about 660 GPM. Upstream pressure was negative ranging between -22 and -63 in. H₂O with an average value of -33.8 in. H₂O. The flow with the former free discharge of the force main averaged 670 GPM. It appears that the U-tube at Station 7 with normal pump operation and with an aspiration of about 4 CFM increased the system head by about 55 in. H₂O which resulted in an 11% loss in capacity. With two pump operation and normal aspiration at 8 CFM upstream pressure ranged between 80 and 100 in. H₂O. Flow was reduced from a free discharge capacity of 920 GPM to 795 GPM or about a 14% loss in capacity. Aspiration at 795 GPM was between 7 and 8 CFM which is equivalent to an air-water ratio of .07. For normal single pump operation viz: a flow of 600 GPM and an aspiration of 4 CFM the air-water volume ratio was .05.

The entrance elbow was modified in the same manner as previously described for Station 5 U-tube, but did not appear to improve transfer. However, the lag between sewage flow and the start of aspiration was reduced. In the case of Station 7, the reduction was from an average 110 seconds with the original configuration to between 30 and 40 seconds with the new elbow. Figure 31 is the daily plot of D.O. at Station 7A before and after activation of the aeration devices. Before activation of the aeration devices D.O. in Station 7A ranged from 0 to a high of 1.7 mg/l with an average value of .62 mg/l. After activation of

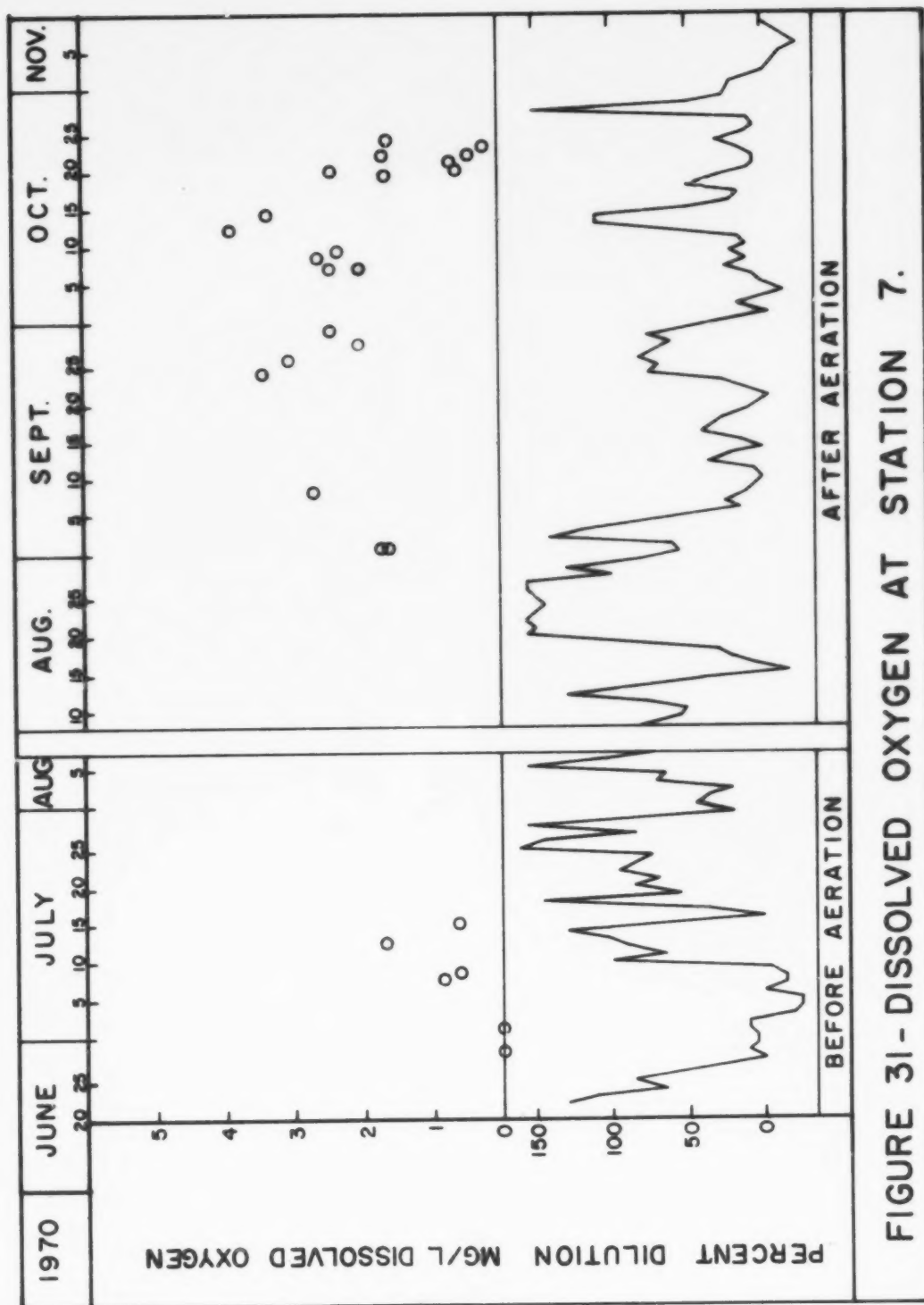


FIGURE 31- DISSOLVED OXYGEN AT STATION 7.

the U-tube, D.O. ranged from a low of 0.2 mg/l with a high of 3.8 mg/l with an average value of 2.1 mg/l. It should be noted here that before activation of the U-tube samples had to be taken immediately after flow from the force main stopped and are not fully representative of conditions during the force main discharge. The same is true for sulfide, BOD₅ and COD samples. Figure 32 is the daily plot of sulfides at Station 7A. Before activation of the U-tube, dissolved sulfides (S₈₅) ranged from zero to a high of .91 mg/l with an average value of .26 mg/l. After activation of the U-tube, dissolved sulfides (S₈₅) in 7A ranged from zero to a high of .21 mg/l with an average value of .06 mg/l. Figure 33 is the hourly plot of sulfides in Station 7A. Figure 34 is the daily plot of BOD₅ and COD at Station 7A before and after activation of the U-tube. Before activation of the U-tube, BOD₅ ranged from a low of 88 mg/l to a high of 178 mg/l with an average value of 126 mg/l. COD ranged from a low of 158 mg/l to a high of 385 mg/l with an average value of 237 mg/l. After activation of the U-tube, BOD₅ ranged from a low of 31 mg/l to a high of 160 mg/l with an average value of 96 mg/l. COD ranged from a low of 105 mg/l to a high of 268 mg/l with an average value of 186 mg/l. The apparent reduction attributable to the U-tube was 77% for dissolved sulfides, 22% for COD and 24% for BOD₅. Table 4 is a tabulation of IOD and D.O. taken at Stations 7B and 7A. This data reflects the original configuration of the U-tube and consequently relates to other downstream data taken during the demonstration. No instream data was taken after modification of the elbows of the two U-tubes since aspiration rates were not increased. IOD ranges from a low of 1.0 mg/l to a high of 5.5 mg/l with an average value of 3.1 mg/l. D.O. ranged from a low of 0.4 mg/l to a high of 3.8 mg/l with an average value of 1.7 mg/l. There is good correlation between the D.O. recorded in Figure 31 for Station 7A after activation of U-tube as originally configured and the D.O. recorded in Table 4.

VENTURI AND ASHBROOK AERATORS

The pumping rate through the in-line Venturi ranged between 920 and 1080 GPM. During test hours and dry weather, the pumping cycle ranged between four and six minutes, and the interval between pumping from seventeen to twenty

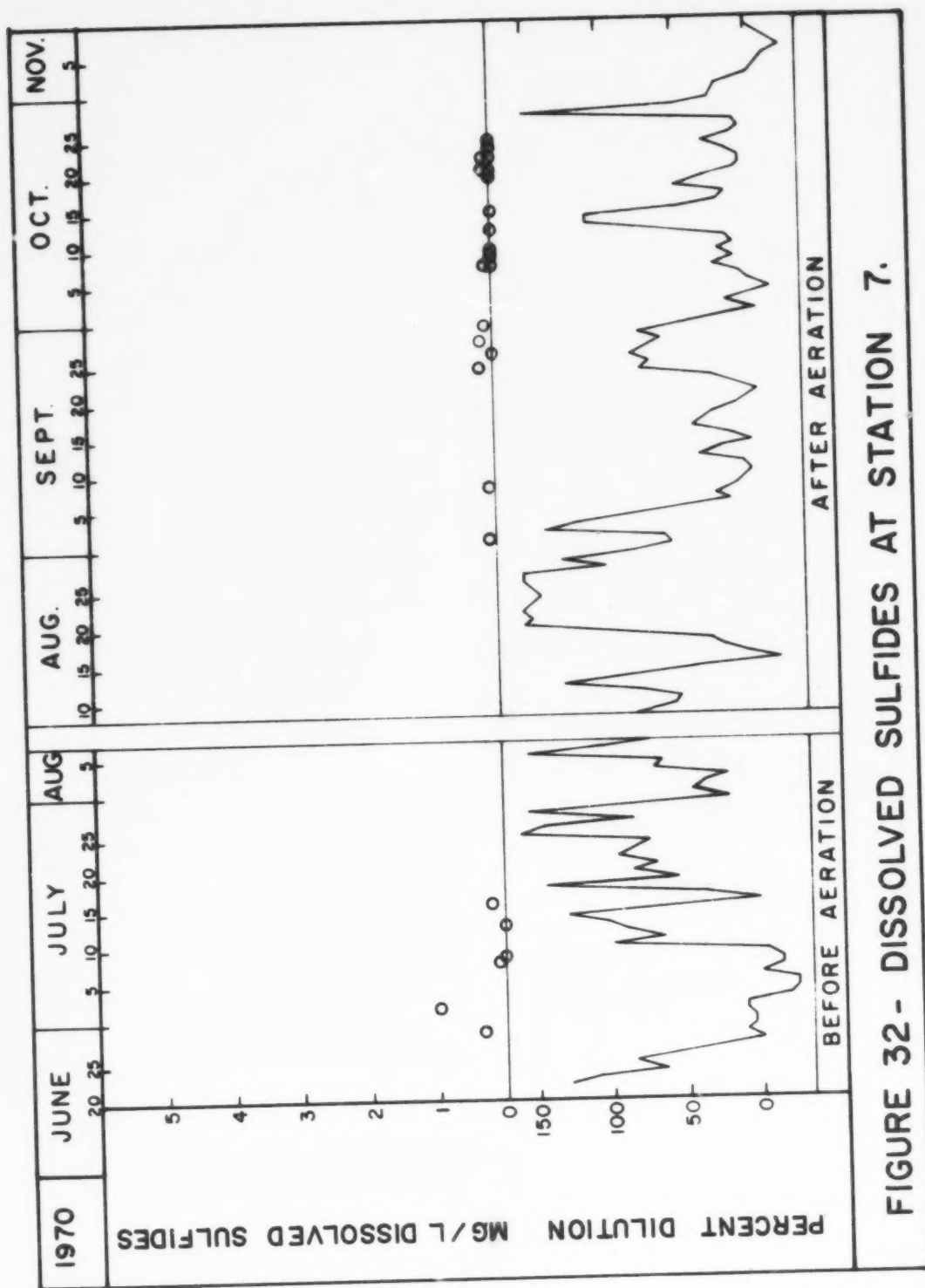


FIGURE 32 - DISSOLVED SULFIDES AT STATION 7.

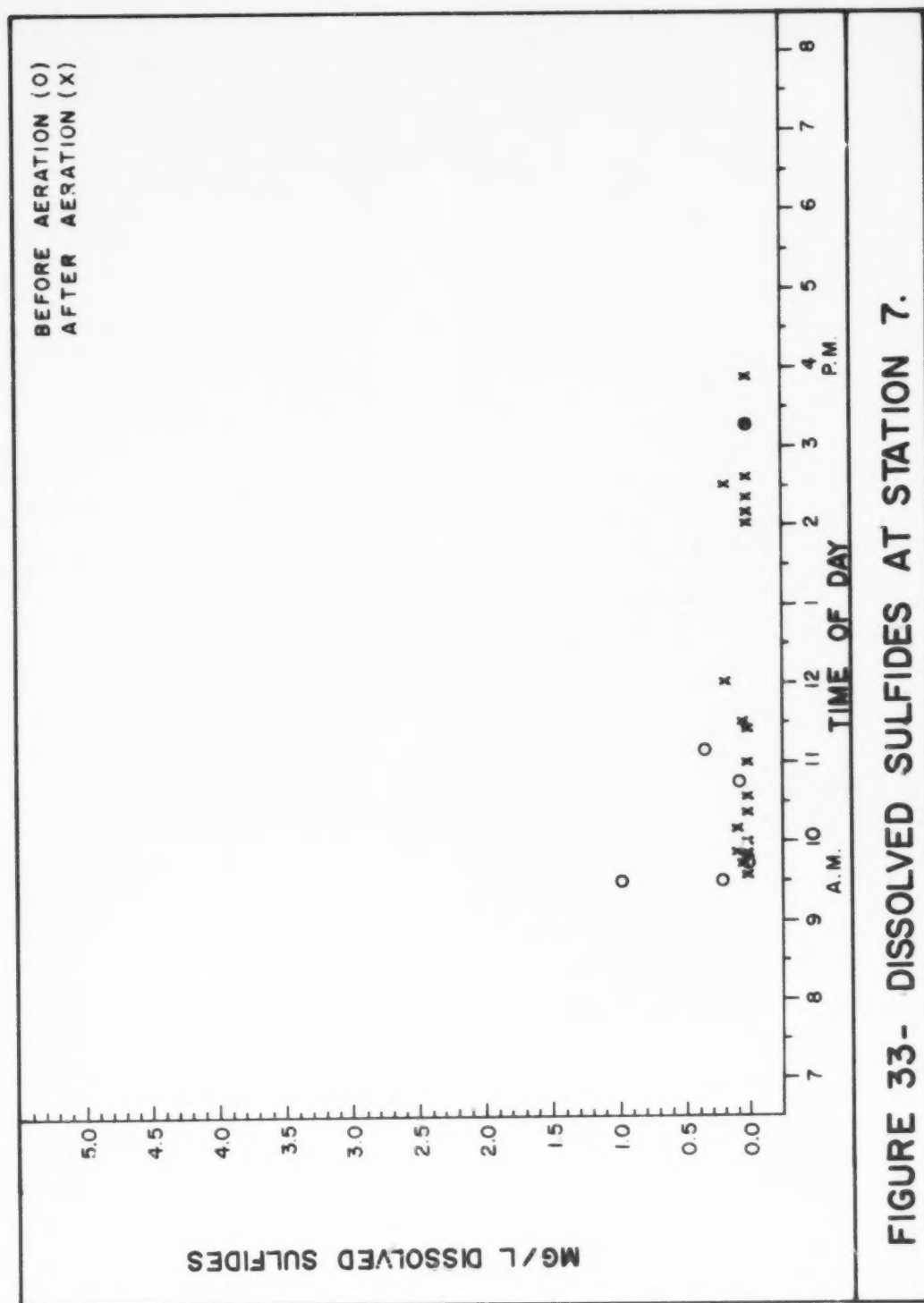


FIGURE 33- DISSOLVED SULFIDES AT STATION 7.

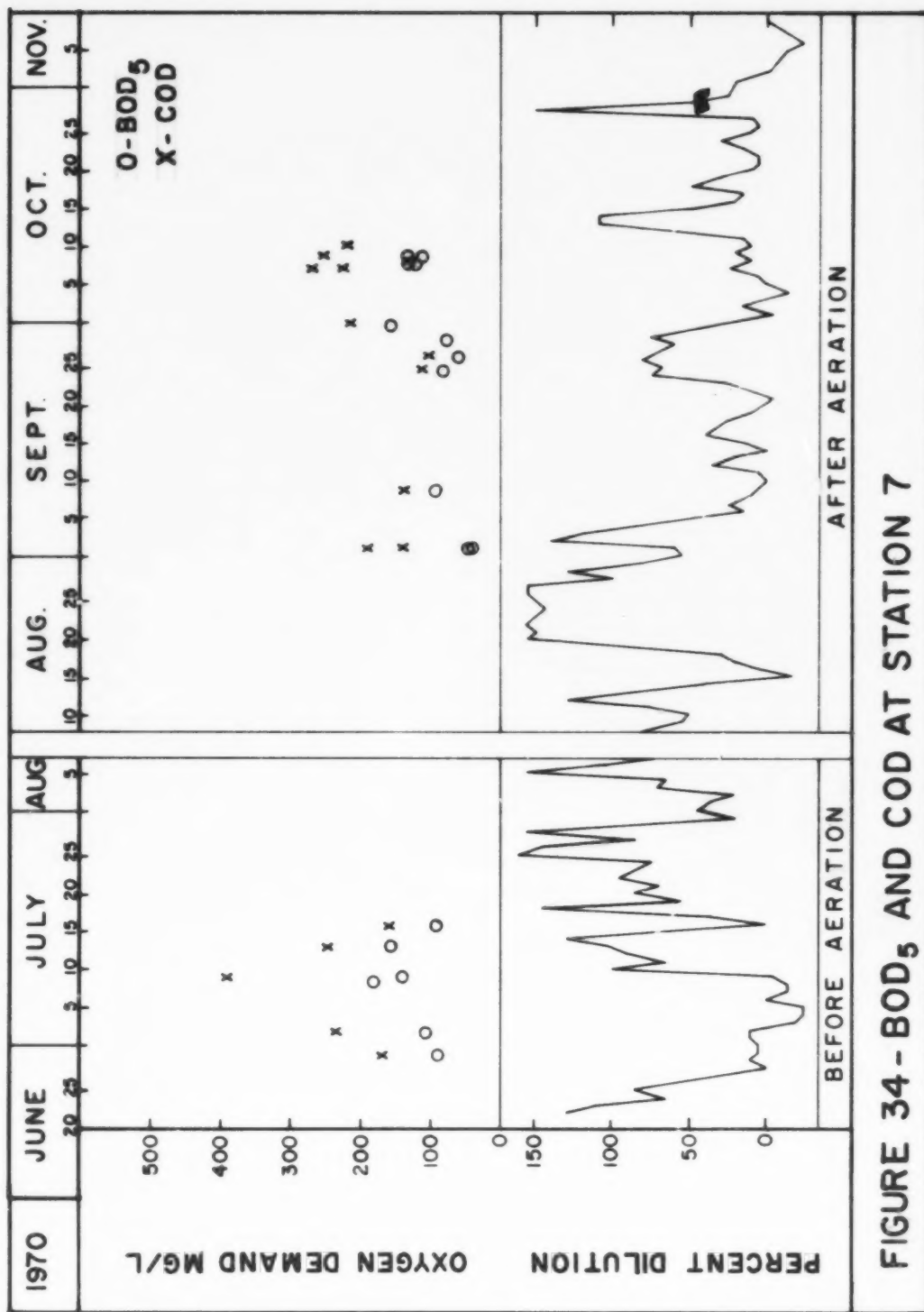


FIGURE 34 - BOD₅ AND COD AT STATION 7

TABLE 4

IOD AT STATION 7B, UPSTREAM
OF THE VENTURI AND D.O. IN 7A
RECEIVING THE U-TUBE DISCHARGE

<u>Date</u> <u>----</u>	<u>Sta. 7B</u> <u>IOD mg/l</u>	<u>Sta. 7A</u> <u>DO mg/l</u>	<u>Transfer</u> <u>mg/l O₂</u>
10/7/70	1.3	2.0	3.3
10/7/70	2.2	2.4	4.6
10/12/70	1.8	3.8	5.6
10/14/70	1.0	3.3	4.3
10/19/70	2.9	1.6	4.5
10/20/70	4.5	0.6	5.1
10/20/70	3.3	2.4	5.9
10/21/70	3.4	0.7	4.1
10/22/70	5.5	0.4	5.9
10/22/70	3.4	1.7	5.1
10/23/70	3.9	0.2	4.1
10/24/70	3.5	1.6	5.1
Average	3.1	1.7	4.8

Air/Water Volume Ratio 0.04

minutes. Preliminary tests disclosed that the Ashbrook device would not aspirate a measureable volume of air. Pressure drop across the Ashbrook was 10 psi and upstream pressure was 12.5 psi with a flow of 910 GPM. Because of the failure of the Ashbrook to aspirate and the impracticability of supplying air in bottles only the in-line Venturi was activated during this demonstration.

Sampling taps were located immediately upstream and downstream of both the in-line Venturi and the Ashbrook device. The location of the downstream tap proved to be too close to the Venturi outlet to provide for absorption of oxygen or the oxidation of sulfides. Transfer of oxygen across the in-line Venturi based on eight samples at the taps was consistently less than 1 mg/l, however, when a 50 ft length of garden hose was imposed between the downstream tap and the sampling bottle, transfer in five samples averaged above 2 mg/l. Obviously no correlation exists between a 50 ft length of 3/4 in. garden hose and several hundred feet of 8 in. force main and this data is meaningless to this demonstration. On the other hand it serves to prove that the reaction was incomplete at the tap provided downstream of the Venturi and designated Station 32. COD and sulfides run on these samples from Station 32 were in many instances higher and never significantly lower than corresponding measurements run on samples from Station 31 immediately upstream of the Venturi despite an aspiration of 5 to 6 CFM equivalent to an air-water volume ratio of .04. Station 30 receives the discharge from the in-line Venturi at Stations 31-32. The three to seven foot drop from this force main to the wet well water surface was not eliminated. 19 D.O. measurements before activation of the Venturi ranged from a low of 0.7 mg/l to a high of 3.0 mg/l and averaged 2.03 mg/l. 13 D.O. measurements taken after activation of the Venturi ranged from a low of 1.0 mg/l to a high of 3.8 mg/l and averaged 2.33 mg/l. This would appear to credit the in-line Venturi with a gain of 0.3 mg/l or no significant improvement over the aeration realized from the fall and splash of a high force main discharge. In any event the persisting stripping of hydrogen sulfide brought violent complaints from residents in the vicinity and forced curtailment of sampling from Station 30.

SECTION VI

SUMMARY OF RESULTS

Tables 5 and 6 are tabulations of mean values of all measurements of DO, dissolved sulfides (S_{85}), BOD_5 and COD before and after aeration, and the percent reduction in dissolved sulfides, BOD_5 and COD attributable to aeration. These values are derived from measurements in the mixed stream and are not weighted to reflect the percentage of unaerated flow in each sample. Table 5, however, includes a tabulation of the approximate percentage of the flow that issues from the aeration device immediately upstream of the sampling station at the time of sampling. The remainder of the flow into sampling stations at the time of sampling is from untreated gravity sewers previously shown in Figure 2. With the exception of Station 40, these percentages are based on measured depth of flow in gravity sewers and metered flow through the Venturis at the time of sampling. As will be discussed later in this report, it proved impossible to accurately determine a ratio of aerated to untreated sewage in either Station 30 or 40. The tabulations in Tables 5 and 6 list the stations in order of progression from the upstream terminal (Station 7) to the downstream terminal (Station 1) and present a concise summary of the results of this demonstration.

It will be noted that a significant D.O. is recorded before activation of the aeration devices at Stations 7, 40, 6 and 13. This is attributable to the fall with resultant splash and turbulence from the high force main discharges at Stations 7, 30 and 5 and a high gravity drop into Station 40. With the installation of the U-tubes, the falls of seven and four feet, respectively, from the invert of the force mains to the invert of receiving sewer were eliminated from Stations 5 and 7, but the three to seven foot drops from the invert of the force main and gravity sewer to the water surface in the receiving wet wells at Stations 30-40 remained. As would be expected, the stripping of H_2S at Stations 7, 30-40, and 5 was extreme prior to activation of the aeration devices with pronounced odor and clear evidence of corrosive attack. Particularly vehement complaints from residents in the

TABLE 5

TABULATION OF AVERAGE VALUES OF ALL MEASUREMENTS OF DO AND DISSOLVED SULFIDES (S₈₅) BEFORE AND AFTER ACTIVATION OF AERATION DEVICES

Station	% Flow (4) Aerated at Sampling Point	D.O. mg/l (5)		S ₈₅ mg/l (5)		S ₈₅ (5) Reduction
		Before Aeration	After Aeration	Before Aeration	After Aeration	
7B(1)	0	---	0	---	0.27	---
7A(2)	80	0.6	2.1	0.26	0.06	77%
40(3)	40-85	1.9	2.3	0.42	0.11	74%
5B(1)	40-95	---	0	---	0.15	---
5A(2)	96	---	2.5	---	0.06	---
6	95	0.8	1.6	0.51	0.05	90%
13	79	0.0	0.7	0.30	0.02	93%
2(1)	39	---	---	---	---	---
1	93%	0	1.4	0.63	0	100%

- (1) Stations nonexistent before aeration. 5B and 7B are taps upstream of the Venturi aspirators. Station 2 is the airlift aerator.
- (2) 4 ft and 7 ft fall into stations 7A & 5A, respectively, from force main prior to aeration only. Eliminated by U-tube.
- (3) 3 ft to 6 ft fall into station from gravity sewer before and after aeration.
- (4) This column, except for Station 40, is based on measured flow at the sampling station and is the percentage of total flow (or volume) in the sampling station at the time of sampling issuing from the aerator immediately upstream. The conditions controlling at Station 40 are explained in the text.
- (5) These values are as measured in the mixed stream and are not weighted to reflect the percentage of aerated flow in the samples.

TABLE 6
TABULATION OF AVERAGE VALUES OF ALL
MEASUREMENTS OF COD AND BOD5 BEFORE
AND AFTER ACTIVATION OF THE AERATION
DEVICES

Station	COD			BOD5		
	Before Aeration	After Aeration	Reduction	Before Aeration	After Aeration	Reduction
7B	---	220	---	---	103	---
7A	237	186	22%	126	96	24%
40	306	251	18%	174	152	13%
5B	---	352	---	---	221	---
5A	---	319	---	---	194	---
6	296	260	12%	151	125	17%
13	315	250	21%	176	150	15%
1	310	208	33%	169	128	24%

vicinity of Stations 30-40 had forced the Parish to seal the covers of these wet wells and run a 6 in. vent under a railroad embankment out into an open field. Opening these sealed covers at Station 30-40 to take samples and measurements brought immediate and violent opposition which persisted despite assurances that the work would be of short duration and was specifically aimed at reducing and possibly eliminating the odor.

Unfortunately after aeration, even with dissolved sulfides reduced 74% to a mean value of 0.1 mg/l, some odor persisted and sampling had to be curtailed at Station 30-40. This appears to confirm observations by Pomeroy and Bowlus (6) to the effect that, while concentrations at or below 0.1 mg/l dissolved sulfides may be acceptable in a smoothly flowing gravity sewer with a nominal pH (about 7), concentrations significantly below 0.1 mg/l dissolved sulfides can produce totally unacceptable levels of H_2S in the sewer atmosphere if there is turbulence, particularly if the pH is at or below 7.

Contrary to the situation persisting at Stations 30-40, the U-tubes at Stations 5 and 7 are set with the invert of their discharge practically level with (0.1 ft above) the invert of the receiving sewer. The aerated stream from the U-tube blends very smoothly with the untreated stream and there was no detectable odor of H_2S in either manhole even though dissolved sulfides as high as 0.21 mg/l on one occasion were recorded in the combined (aerated and untreated) stream. Table 5 gives good indication of the continuing oxidation of the dissolved sulfides in the gravity sewer downstream of the aeration device. At Station 7A, the discharge manhole directly receiving the aerated discharge of that U-tube, the mean D.O. was 2.1 mg/l and the reduction in dissolved sulfides was 74%. This amounted to a decrease from a mean of 0.26 mg/l before aeration to a mean of 0.06 mg/l after aeration. At Station 6, 370 ft downstream of the discharge of the second U-tube (Station 5A), the mean D.O. decreased to 1.6 mg/l (from 2.5 at 5A) and the reduction in dissolved sulfides was 90%. This amounted to a decrease from a mean of 0.51 mg/l before aeration to a mean of 0.05 mg/l after aeration. At Station 13, 1450 ft downstream of 5A, the mean D.O. dropped to 0.7 mg/l and the reduction in dissolved sulfides was 93%. This amounted to a decrease from a mean

0.30 mg/l before aeration to 0.02 mg/l after aeration by the U-tube.

Contrasting the sulfide concentrations in the system before and after aeration, aside from the significant overall reduction, it will be noted that before aeration, except for Station 13, there was a typical consistent build-up as the flow progressed downstream. After aeration, except for Station 40, there was a consistent drop as the flow progressed downstream. The dip in sulfide concentration at Station 13 before activation of the aeration devices appears to reflect the transfer of oxygen to and the stripping of H_2S from the sewage by the seven foot fall from the force main into Station 5A and the continuing oxidation of sulfides in the sewer between Stations 6 and 13. This is supported by the measured D.O. before installation of the U-tube of 0.8 mg/l and 0.01 mg/l at Stations 6 and 13, respectively, before activation of the aeration devices. As shown by Table 5, the percentage of aerated sewage in any sample at the time of sampling is, except for Station 40, based on the measured flow in the sampling station at the time of sampling. In the cases of both Stations 30 and 40, which are two 9 ft 0 in. diameter bottom connected wet wells with a combined volume on the order of 5000 gals. that receive the continuous flow of two 10 in. and one 8 in. gravity sewers plus intermittent flows from an 8 in. and 10 in. force main, the percentage of aerated sewage in any sample could range from 40% or less, to 85%. It can be assumed that percentage approaches the higher value because of the fact that samples were consistently taken only at high water level and in the case of Station 40, during or immediately following inflow from Station 7. However, the significance of data from Station 40 is somewhat questionable. In all other stations the rate of flow of contributing gravity sewers, the flow through the Venturi aspirators and the flow in the sewer receiving the combined flows could be readily determined.

Table 6 tabulates the mean values of all BOD_5 and COD measurements taken before and after activation of the aeration devices. There appears to be a significant reduction attributable to each aeration device and a significant cumulative reduction after aeration at all stations. There does not appear to be a really clear correlation between sulfides and either BOD_5 or COD. With

the degree of treatment involved in this demonstration, no substantial reduction in BOD₅ or COD could be anticipated.

The low average BOD₅ and COD measurements tabulated in Table 6 show quite clearly the heavy residual dilution from persistently heavy rainfall encountered both before and after activation of the aeration devices. This was previously illustrated in Figure 14. Figure 14 would appear to indicate a substantially heavier dilution in the period before activation of the aeration device, however, instream measurements and sampling during both periods were limited to times when the flow was at or near normal and consequently the residual effects of dilution were probably more nearly equal. It can be presumed that dilution did not seriously penalize and certainly did not unduly favor the performance of the aeration devices.

The spacing of Station 2 in relation to Station 5 was based on an empirical method developed by C.L. Swanson (7). The method is evaluated by application of data taken at Stations 5A and 13.

Swanson (7) hypothesized that oxygen demand in a sewer originates from:

1. Oxidation of sulfides produced in the slime layer; Pomeroy and Bowlus (6).
2. Oxidation of sulfides produced in the flowing stream, Pomeroy (8).
3. Oxidation of sulfides and other materials produced in deposited solids in the sewer.
4. BOD demand of sewage (10).
5. Trickling filter effect in which the sewer surface is analogous to the rock surfaces of a trickling filter under submerged flow conditions.

Since no BOD reduction was observed between Stations 6 and 13 (see Table 6) it was assumed that the trickling filter effect was nil and accordingly this factor was eliminated. Since deposited solids were minimal in the test reach of sewer this factor was eliminated.

It was assumed that sufficient oxygen would be available in the sewer atmosphere to meet the demand and that transfer would be dependent on the width of the air-water interface and directly proportional to the D.O. deficit (D.O. at saturation minus the D.O. of the sewage stream) and the Reynolds Number as demonstrated by Davy (9). No attempt was made to correct oxygen transfer for temperature or oxygen concentration in the sewer atmosphere.

The input for calculation of required spacing by Swanson's method (7) is:

BOD at Station 5A (Table 6)	194 mg/l
D.O. at Station 5A (Table 5)	2.5 mg/l
Average instream temperature	29° C
D.O. at Station 13 (Table 5)	0.7 mg/l
Deoxygenization constant (K_{20})	0.15
Sewer Diameter	21 in.
Average Depth of Flow	11 in.
Average velocity	2.12 FPS

On the basis of data from Stations 5A and 13 the calculated spacing by Swanson's method (7) would be about 2200 ft. The actual distance is 1500 ft. This apparent discrepancy must be viewed in the light of the fact that roughly .15 MGD of the 1.4 MGD flow into Station 13 is from four untreated laterals entering the system between Stations 6 and 13. As a consequence 11% of the flow into Station 13 is not reflected in the data from Station 5A and the calculated spacing should exceed the actual distance by an appreciable amount. No data was taken from the four laterals and consequently it cannot be determined if or to what extent the build up in BOD_5 between Stations 6 and 13 (See Table 6) is attributable to the four untreated laterals. On the other hand, since the average D.O. before aeration was 0.8 mg/l at Station 6 and zero at Station 13, (see Table 5) it can be assumed that the D.O. of the four laterals approached zero or possibly carried an oxygen demand. If it is assumed that the 11% contribution of the four laterals was at zero D.O. and the D.O. at Station 5A adjusted by simple proportion to 2.2 D.O. ($.89 \times 2.5 = 2.2$) then the calculated spacing by Swanson's method (7) would become 1491 ft or very nearly the actual spacing (1500 ft) between Stations 5A and 13.

SECTION VII

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SECTION VIII

APPENDICES

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APPENDIX A

COMPUTER PROGRAM FOR TOTAL DISSOLVED SULFIDE CALCULATIONS

To attempt hand calculation of total dissolved sulfides from electrochemical measurements in a project of this size would be impractical. Accordingly, a reliable computer program is essential to this method of measurement.

The program language is IBM 1130/1800 Basic Fortran IV. The computer employed was an IBM 1130 8K with disc, a 1442 card reader-punch and an 1132 printer.

All field data was ultimately punched on cards, however, only three variables (chlorides, pH and absolute $MvS^=$) are used in the program to compute the total dissolved sulfides.

The program derives from procedures outlined in the Orion Reference Manual for the 94-16 sulfide electrode employed in this demonstration. A reference curve corresponding to Figure 5 of the Orion 94-16 Manual was determined generating SULIA (sulfide ion activity $As^=$). The Factor f for converting sulfide ion activity to total dissolved sulfides is computed from precise pH measurement and approximate ionic strength on the basis of Table 3 in the Orion 94-16 Manual. The computed value of dissolved sulfide concentration is then punched on the data card to which may be added any additional pertinent field data for subsequent listing and correlation.

```

*LOGICARD.1132PRINTER=DISK)
*LIST ALL INTEGERS
*ONE WORD INTEGERS
*NAME TSULF
*ARITHMETIC TRACE
*TRANSFER TRACE
REAL MV
INTEGER STA,DATE(3),TIME
DIMENSION ARG(10),VAL(10)
ARG(1)=0
10 FORMAT(11X)
1 STATION DATE IONIC CONCTN SULPHIDE PPM SULPHIDE
TIME CONCTN MV ACTIVITY PH CHLORIDES
3 STRENGTH FACTOR CONCTNM) SULPHIDE')
20 READ(2,30) (DATE(1),1-1,2,STA,TIME,PM,MV
30 FORMAT(12,A2,1A,1A,13A,F5.2,F5.0)
DATE(1)=70
CLPM=200.
X1=78.
X2=84.
V1=ALOG(0.001)
Y2=ALOG(0.100)
SLOPE=(Y2-Y1)/(X2-X1)
B=Y1-SLOPE*X1
Y=SLOPE*PM+8
SULF=EXP(Y)
SULF=CLPM/S9657.
ARG(1)=1
ARG(2)=2
ARG(3)=4
ARG(4)=6
ARG(5)=7
ARG(6)=8
ARG(7)=10
ARG(8)=12
ARG(9)=14
ARG(10)=16
DO 100 L=1,4
GO TO (52,54,56,58),L
52 VAL(1)=8.9E19
VAL(2)=8.9E19
VAL(3)=8.9E19
VAL(4)=9.7E7
VAL(5)=1.7E6
VAL(6)=1.7E6
VAL(7)=8.0E2
VAL(8)=10.3
VAL(9)=3.74
VAL(10)=1.
GO TO 40
54 VAL(1)=8.9E19
VAL(2)=8.9E19
VAL(3)=8.9E19
VAL(4)=9.7E7
VAL(5)=1.7E6
VAL(6)=9.2E4
VAL(7)=8.3E2
VAL(8)=10.3
VAL(9)=3.74
VAL(10)=1.
GO TO 60
56 VAL(1)=8.9E19
VAL(2)=8.9E19

```

```

VAL(3)=8.9E11
VAL(4)=9.8E7
VAL(5)=9.7E6
VAL(6)=9.7E4
VAL(7)=8.8E2
VAL(8)=1.0E3
VAL(9)=9.7E
VAL(10)=1.
GO TO 60
58 VAL(1)=8.9E19
VAL(2)=9.8E15
VAL(3)=8.9E11
VAL(4)=9.8E7
VAL(5)=1.9E6
VAL(6)=1.1E5
VAL(7)=1.0E3
VAL(8)=1.3E2
VAL(9)=9.7E
VAL(10)=1.
60 DO I=1,10
  VAL(I)=ALOG(VAL(I))
70 CONTINUE
DO 80 I=1,10
  IF(PH-ARG(I))190,80,80
80 CONTINUE
90 PFAC=VAL(I-1)*(PH-ARG(I-1))*(VAL(I)-VAL(I-1))/(ARG(I)-ARG(I-1))
92 GO TO (22,96,96,98),I
94 B=EXP(PFAC)
96 GO TO 100
98 C=EXP(PFAC)
100 CONTINUE
ARG(1)=10.E-4
ARG(2)=10.E-3
ARG(3)=10.E-2
ARG(4)=10.E-1
VAL(1)=A
VAL(2)=B
VAL(3)=C
VAL(4)=D
DO 200 I=1,4
  PH=ARG(I)
  XION=ARG(I)
  VAL(I)=VAL(I-1)*(ARG(I)-ARG(I-1))
  PFAC=VAL(I)*XION
  SCTM=SULIA*PFAC
  SCTPM=SCTM+3204.
  WRITE(3,500) STA,(DATE(I),I=1,3),TIME,MV,SULIA,PH,CLPPH,XION,PFAC
1. SCTM=SCTPM
500 FORMAT(9X,A2,A3,I2,110,F8.0,2X,E10.3,F7.2,3X,E10.3,F10.4)
  WRITE(2,600) SCTPM
  WRITE(6,600) SCTPM
  GO TO 20
200 CONTINUE
END

VARIABLE ALLOCATIONS
ARG -C012 VAL -C016 MV -C028 PH -C02A CLPPH-C02C X1 -C02E X2 -C030 Y3 -C032 Y2 -C034 SLOPE-C036
B -C038 TV -C03A SULIA-C03C XION -C03E PFAC-C040 A -C042 C -C044 D -C046 SCTM -C048 SCTPM-C04A
STA -C050 DATE -C053 TIME -C054 I -C055 L -C056

```


APPENDIX B

FIELD DATA

Data on pages 86 through 88, inclusive, is before activation of the aeration devices.

Data on pages 89 through 92 represents conditions after activation of the aeration devices.

DEFINITION OF COLUMN HEADINGS

Date - The month, day and year of the in-stream measurement and sample.

Station - The Station No. (See Figure 2).

Time - The hour and minutes based on the 24 hour clock.

Depth (inches) - The depth of flow in the gravity sewer.

Temp (°F) - The instream temperature of the sewage.

pH - The pH measured instream.

Sulfide Activity (MV) - The sulfide activity in absolute millivolts measured instream.

D.O. - The D.O. run on a 300 ml sample taken simultaneous with instream measurement of pH and MV $S^{=}$.

BOD₅ - The five day BOD run on a 300 ml sample taken simultaneous with instream measurement of pH and MV $S^{=}$.

COD - COD run on the same sample as BOD₅.

EBOD - BOD₅ adjusted from the incubation temperature (20°C) to the actual instream temperature.

Standard Sulfides (S₈₅) - mg/l total dissolved sulfides adjusted to a standard temperature of 85° F.

Effective sulfides - mg/l total dissolved sulfides in stream at stream temperature.

71376	40	1048	89.5	7.45	582	2.4	162	317	4.77	0.77	0.97
71377	40	1330	89.0	7.40	582	2.4	162	317	4.77	0.77	0.97
72076	40	1400	84.0	7.00	516	0.7	178	289	3.23	0.04	0.04
72476	40	1013	83.0	6.98	563	1.6	197	407	3.65	0.38	0.38
72676	40	1200	82.0	7.05	570	2.4	161	233	3.04	0.39	0.39
72677	40	1200	82.0	7.05	570	2.4	161	233	3.04	0.39	0.39
72776	40	840	82.0	7.05	570	2.4	161	233	3.04	0.39	0.39
72777	40	840	82.0	7.05	570	2.4	161	233	3.04	0.39	0.39
73776	40	1354	85.0	7.23	580	2.2	170	400	3.65	0.17	0.17
73777	40	900	85.0	7.13	480	2.2	170	400	3.65	0.17	0.17
75076	40	800	82.0	7.24	543	2.5	159	268	2.68	0.00	0.00
75077	40	815	83.0	7.23	543	2.5	159	268	2.68	0.19	0.17
75078	40	1250	85.0	7.41	586	1.9	144	166	0.14	0.14	0.14
75079	40	1250	85.0	7.41	586	1.9	144	166	0.14	0.14	0.14
75079	40	1310	87.0	7.28	550	1.6	83	159	0.31	0.31	0.31
75079	40	1310	87.0	7.28	550	1.6	83	159	0.31	0.31	0.31
75079	40	1310	87.0	7.28	550	1.6	83	159	0.31	0.31	0.31
75079	40	1700	86.0	7.23	535	1.7	137	275	2.75	0.25	0.25
75079	40	1700	86.0	7.23	535	1.7	137	275	2.75	0.25	0.25
80476	40	1300	84.0	7.08	540	1.6	223	368	4.56	0.08	0.08
80477	40	1300	84.0	7.08	540	1.6	223	368	4.56	0.28	0.28
80478	40	1300	84.0	7.08	540	1.6	223	368	4.56	0.07	0.07
80479	40	1300	84.0	7.08	540	1.6	223	368	4.56	0.07	0.07
80576	40	1646	82.0	7.00	550	2.6	184	323	3.34	0.02	0.02
80577	40	1646	82.0	7.00	550	2.6	184	323	3.34	0.02	0.02
80578	40	1000	86.0	6.98	335	2.7	237	464	4.64	0.16	0.16
80579	40	1000	86.0	6.98	335	2.7	237	464	4.64	0.16	0.16
80776	40	1224	87.0	6.84	445	2.3	170	400	3.65	0.63	0.70
80777	40	1500	86.0	6.80	440	2.2	170	400	3.65	0.54	0.56
80778	40	1735	85.0	7.11	555	2.2	192	316	3.62	0.24	0.24
80779	40	1735	85.0	7.11	555	2.2	192	316	3.62	0.24	0.24
82676	32	1000	87.0	7.19	370	0.5	337	418	5.62	6.07	6.07
82677	32	1000	87.0	7.19	370	0.5	337	418	5.62	6.07	6.07
82678	32	1315	86.5	7.13	580	0.7	146	470	3.23	0.37	0.37
83076	32	800	86.5	7.13	555	0.2	322	512	6.50	0.26	0.27
83077	32	800	86.5	7.13	555	0.2	322	512	6.50	0.26	0.27
83078	32	1030	86.0	7.01	582	0.0	357	660	4.99	6.19	6.19
83079	32	1030	86.0	7.01	582	0.0	357	660	4.99	6.19	6.19

90

91

